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HIGH ALTITUDE LONG ENDURANCE (HALE) PLATFORMS FOR TACTICAL WIRELESS COMMUNICATIONS AND SENSOR USE IN MILITARY OPERATIONS

by

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U.S. military forces are transitioning to network centric operations, as described in Joint Vision 2010 and Joint Vision 2020. Warfighting elements will function as individual nodes in a global information grid with an end-to-end infrastructure that provides information on demand to warfighters, policy makers, and support personnel. This transition will place additional demands on wireless communications and Intelligence, Surveillance, and Reconnaissance (ISR) systems. However, current and planned space-based communications solutions are costly and have significant shortfalls. Likewise, ISR systems will have difficulty fulfilling near real-time requirements and sensor-to-shooter roles. One possible solution is through the use of emerging stratospheric platforms. In the area of communications and ISR support, this thesis; reviews the Services' doctrines and future warfighting needs, identifies available space-based systems along with their shortfalls, and defines support capabilities from the stratospheric environment. It then provides an in-depth review of emerging high altitude long endurance (HALE) platforms, analyzes HALE platforms survivability, provides a concept of operations (CONOPS) for HALE employment, and performs a HALE platform comparative analysis.

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ABSTRACT

U.S. military forces are transitioning to network centric operations, as described in Joint Vision 2010 and Joint Vision 2020. Warfighting elements will function as individual nodes in a global information grid with an end-to-end infrastructure that provides information on demand to warfighters, policy makers, and support personnel. This transition will place additional demands on wireless communications and Intelligence, Surveillance, and Reconnaissance (ISR) systems. However, current and planned space-based communications solutions are costly and have significant shortfalls. Likewise, ISR systems will have difficulty fulfilling near real-time requirements and sensor-to-shooter roles. One possible solution is through the use of emerging stratospheric platforms. In the area of communications and ISR support, this thesis; reviews the Services' doctrines and future warfighting needs, identifies available space-based systems along with their shortfalls, and defines support capabilities from the stratospheric environment. It then provides an in-depth review of emerging high altitude long endurance (HALE) platforms, analyzes HALE platforms survivability, provides a concept of operations (CONOPS) for HALE employment, and performs a HALE platform comparative analysis.

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I. INTRODUCTION

A. PURPOSE OF RESEARCH

The purpose of this research is to determine whether emerging technologies involving High Altitude Long Endurance (HALE) platforms have significant military capabilities for Network Centric Warfare in terms of providing wireless connectivity and Intelligence, Surveillance, and Reconnaissance (ISR) support to tactical warfighters. Specifically, the authors wish to answer the following questions. What is the current status of military and commercial HALE developmental efforts? And, how well are HALE platforms suited to fulfill emerging requirements and satisfying known warfighter deficiencies in current requirements?

In order to do this, several general areas of research are covered. First, space-based platforms are identified that currently support wireless connectivity and ISR missions. These platforms are analyzed to identify where there are limitations in the move towards Network Centric Operations using both current and planned space-based systems. Secondly, the research will identify mission areas where HALE systems offer unique capabilities over space-based and lower altitude platforms. Third, specific HALE systems in development are described to show their current status, advantages, disadvantages, and challenges. Fourth, analysis in terms of survivability and concept of operations (CONOPS) will show the operational potential for HALE craft in the communications and ISR roles. Fifth, comparative analysis will be presented to show the differences between the various HALE systems researched. Finally, the authors will provide their views of the overall potential of HALE systems and give their recommendations on how the Navy and Marine Corps should proceed in integrating these systems into future architectures.

B. BACKGROUND

There is a new concept being used to describe the way US forces must organize and fight in the information age. The idea is called "Network Centric Warfare" and is defined in a variety of ways. One definition describes it as "an information superiority-enabled concept of operations that generates increased combat power by networking sensors, decision makers, and shooters to achieve shared awareness, increased speed of command, higher tempo of operations, greater lethality, increased survivability, and a degree of self-synchronization." [Alb00, p. 2]

In the context of this thesis, it relates to two themes. First, it essentially means that warfighters are individual nodes with connectivity to the entire defense information infrastructure. They are able to push or pull information as needed to maintain consistent real-time battlespace awareness. This connectivity allows for immediate request and response to issues such as transmitting commands to subordinate units or requesting support from higher headquarters. This also provides for fast tempo operational capabilities with a synergistic effect on an opponent. Second, it means that there must be an ISR architecture in place that feeds the information needs directly to the warfighters in a near real-time (NRT) capacity. This ISR information must be easily assessable to all those in the network.

Network Centric ideas tie neatly into traditional warfighting theories. Network Centric Warfare can have a profound effect on the ideas of "fog" and "friction" defined by the historical war theorist, Carl Von Clausewitz. The "fog" of war is the uncertainty in warfare that is derived from a lack of accurate intelligence. [How89, pp. 117-119] By implementing a Network Centric architecture, it is possible to reduce, although not entirely eliminate, the difficulties of fog by improving capabilities for NRT accurate battlespace awareness with capabilities that currently do not exist.

In terms of how these Network Centric capabilities can enhance the means of command and control, the following two historical theories apply. First, Network Centric Warfare can decrease Clausewitz' concept of "friction" on the battlefield. "Friction" relates to the difficulties commanders encounter when trying to implement their

command and control decisions under the cloud of uncertainty or fog that accompanies war [How89, pp. 117-119]. By maintaining a consistent operating picture and continued connectivity with the command structure, commanders will be able to better direct their forces under reduced fog. Unlike past conflicts, where tactical connectivity seldom went farther than line-of-sight, this new capability will provide worldwide reach for commanders in the tactical arena.

Second, in terms of a more modern theory on warfare, Network Centric advantages can be expressed in terms of Col. John Boyd's "OODA loop" theory. Col. Boyd was a US Air Force fighter pilot who transformed his views of tactical aerial combat into a theory on the decision-making process in combat, and then applied it to all levels of warfare. "He contends that all rational human behavior, individual or organizational, can be depicted as a continual cycling through four distinct tasks—observation, orientation, decision, and action (OODA)". [Fad94] The basic concept is that commanders operate inside their own OODA loop and to succeed in combat, they must complete the OODA process faster than their adversaries. By doing this, they can maintain a higher tempo of operations and thus have the advantage because opponents will continually have to repeat the first step of orientation in the command and control cycle, hindering effectiveness. Network Centric Warfare will be a decisive tool in command and control because it will allow commanders to get inside opponents' decision-making process. The knowledge sharing and connectivity will allow commanders to act immediately on the battlefield on a worldwide scale and have their subordinates receive commands immediately.

The **means** to reaching this Network Centric capability is the difficult part today and the focus of this thesis. The end goal is enticing; Network Centric Warfare will enable a Military–Technical Revolution by combining new technologies with innovative operational strategies to fundamentally alter the way US forces fight. This revolution is characterized by: technological change, military systems evolutions, operational innovation, and organizational adaptation. Network Centric Warfare will enable all of these. [Kre92]

The first military power capable of becoming Network Centric will have a distinct advantage on the battlefield.

Two future joint warfighting documents, Joint Vision 2010 (JV 2010) and Joint Vision 2020 (JV 2020), cement the requirements to attain a Network Centric environment. In the area of this research, they identify a number of future needs.

JV 2010 identifies the following:

- Fused Battlefield and Battlespace Visualization
- Accurate interactive picture showing friendly and enemy force dispositions
- Information superiority which provides an uninterrupted flow of information with reachback capabilities
- Lightweight communications gear to increase connectivity for individuals and small units
- Standardized data with an interoperable architecture throughout the theatre of operations
- Fusion of all-source intelligence with widespread sensor-to-shooter capabilities
- Real time information support to command and control architectures. [JV10 p.11-13]

JV 2020 builds upon the JV 2010 vision and adds:

- The development of a concept labeled the "global information grid" which provides for the network centric environment. This will be the end-to-end set of information capabilities that provide information on demand to warfighters, policy makers, and support personnel.
- In terms of Command and Control - Joint Force Headquarters and subordinate headquarters that must have mobility, dispersion, and remain connected with a common standardized network. [JV20, p.12, 39]

The question is where to begin?

Before the operational doctrine or C4I architecture is established to accomplish Network Centric goals there must first be the "infostructure" or hardware, software, protocols, spectrum, etc. that will enable all other actions. In terms of connectivity,

military forces need the physical "plumbing" or throughput capability for the enormous amount of information that must travel over the grid. Ships cannot drag fiber optic cable behind them and land mobile units cannot plug Cat 5 cables into an outlet in the field. This severely limits the options in terms of connectivity mediums and forces warfighters into the wireless realm. Secondly, ISR platforms need to give near real time responsiveness, long dwell times for continuous awareness and high resolution to identify threats, locate targets, and identify friendly forces. This research analyzes a number of space-based and stratospheric platforms to determine a viable direction to take in order to get this required "infostructure".

C. SCOPE AND METHODOLOGY

There were two basic themes behind this research. First the authors wanted to identify the areas where space systems are lacking in providing tactical commanders required communications and ISR assets to effectively conduct operations in the information age. The prevailing thoughts in the space community are to solve these issues with primarily an integrated space architecture, so this thesis revisits the reasons why. Secondly, this thesis reviews the current development of civilian and military programs, which might offer stratospheric solutions to communications and ISR problems.

In defining the shortfalls in space-based communication, a review was conducted of all current and planned space-based communications platforms in three categories; mobile, wideband and protected communications. In each category, the research covered capacity for normal and surge operations and identified areas where users are unsupported. In regards to space-based ISR platforms, an analysis was conducted in generic terms as they relate to the different space regimes and commercial remote sensing technology in order to keep the research unclassified.

In reviewing the currently developing HALE platforms, research was done by numerous means. First, the authors conducted an extensive web search to find the HALE designs that were being planned or developed. Background information was collected from news releases and company briefs. Then, various program offices were contacted to

speak with qualified representatives on each HALE project team. Finally, a number of on-site visits were conducted to government and civilian research facilities and corporations that are conducting HALE development and stratospheric satellite augmentation development. This provided the ability to accurately determine how these systems were progressing and to get the required data to conduct trade studies to conclude the research.

The authors did not set out with the intent to discredit space capabilities. The goal was to show that the services need an integrated solution to known deficiencies using various communications and ISR mediums to meet future warfighting needs. The desire was to determine whether developing HALE systems actually were capable, suitable, and feasible to perform niche services in the drive to a Network Centric Environment.

D. ORGANIZATION OF STUDY / LIST OF CHAPTERS

This research is comprised of nine chapters. The first three provide essential background information and identify space-based communications systems and ISR shortfalls. Chapters four through six cover in detail the stratospheric environment, the specifications of the various HALE platforms and their survivability issues in a combat environment. Chapter seven provides a notional concept of operations (CONOPS) for HALE systems. Chapter eight is a HALE platform comparison analysis. Chapter nine is a wrap-up, including the authors' analytical conclusions and recommendations for utilizing HALE assets. The following bullets provide a summary of the chapters:

- Chapter I – Introduction. This chapter states the purpose of this thesis, gives a detailed background to the themes in the paper, provides the scope of the research and outlines the thesis organization.
- Chapter II – Requirements. This chapter provides the backdrop for determining shortfalls in connectivity and ISR assets. It covers the current and developing doctrines of the four uniformed services. It also shows what the projected shortfalls are in the current and planned bandwidth requirements. Finally, it briefly covers options for procuring extra bandwidth and ISR support from commercial assets.

- Chapter III – Current Communications and ISR Systems. This chapter covers the current and planned space based assets in the inventory for providing connectivity and ISR support. In the wireless communications realm, it will detail each major program in terms of protected, wideband, and mobile communications. In terms of ISR, it details, in an unclassified format, capabilities and deficiencies of space-based platforms in terms of GEO, MEO, and LEO orbits.
- Chapter IV – Stratospheric Considerations. This chapter gives an overview of the stratospheric boundaries and weather patterns. It details various issues where the stratosphere offers significant or unique advantages over space platforms for communications and ISR. It provides comparative analysis between HALE systems and satellites. It lists applicable mission areas where the stratosphere offers unique mission capability to the warfighter.
- Chapter V – HALE Platforms Overview. This chapter begins with a brief categorization of various HALE programs. It then gives an in depth analysis of the developing programs researched in terms of background, specifications, advantages, disadvantages, and challenges.
- Chapter VI – Survivability. This chapter first covers survivability issues relating to satellite utilization. It will then cover parameters on each HALE system's ability to survive in a combat environment. It will detail issues such as; radar cross-section, infrared signature, maneuverability, onboard self protect capabilities, and operational deployment.
- Chapter VII – Concept of Operations. This chapter details potential applications for real-world operational support in both the communications and ISR missions. It covers potential deployment capabilities, range of coverage in-theatre, on-station times, and logistical support requirements.
- Chapter VIII – HALE Comparative Analysis. This chapter provides comparisons between the HALE platforms researched in terms of instantaneous access area, costs, endurance, survivability, feasibility, flexibility, and responsiveness.
- Chapter IX – Conclusions. This final chapter will first summarize the breadth of the research. It will provide the authors conclusions on the viability and importance of integrating HALE platforms into the C4ISR architecture. It then provides recommendations on how the military should proceed in pursuing HALE systems.

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II. REQUIREMENTS

A. INTRODUCTION

Before analyzing the various HALE platforms for military suitability, a review was conducted into what the services will require in the future to conduct military operations. The purpose of this chapter is to outline the services' current and emerging warfighting doctrines as they relate to communications and ISR. Then, previous studies are reviewed that outline the extent to which bandwidth and ISR deficiencies extend. Finally, an analysis is done concerning the potential for tapping commercial space assets in supporting communications and ISR needs.

B. SERVICE REQUIREMENTS

1. Marine Corps

The Marine Corps' current doctrine is *Operational Maneuver From The Sea* (OMFTS), which cements its focus on fighting future battles in the littorals. The Marine Corps has modernizing this doctrine for the 21st century and has renamed it *Marine Corps Strategy 21*.

In the area of intelligence, OMFTS states "Technology that permits rapid dissemination of intelligence products will play an important role." [OMF01, p.12] In the area of command and control it states that communications systems must be designed that "provide units with control over the information they need." [OMF01, p.12] This is a push from communications networks to information networks. *Marine Corps Strategy 21* builds on OMFTS and tries to merge it to support JV 2010 and 2020 visions. In the area of this research, it aims to have "network operational communications, information, and intelligence systems and provide global access capabilities to domestic and international information resources." [MSC21]

The Marine Corps clearly acknowledges the push towards a network centric environment. Network Centric Warfare is becoming a major focus of the Marine Corps Warfighting Laboratory (MCWFL) as it attempts to validate certain global grid concepts. The MCWL is actively engaged in the Kernal Blitz Exercise and recently participated in Fleet Battle Experiment (FBE) India to attempt to validate network centric warfare concepts in an amphibious operation. "It demonstrated a wireless network that could relay voice, data, and imagery over-the-horizon, to Marines at the squad level." [Lin01] A hurdle the Marine Corps faces is the need to have a system to provide this concept theatre-wide on a twenty four hour/ seven days a week (24/7) continuous basis using the full electromagnetic (EM) spectrum. In FBE-India, they used a civilian aircraft as the relay platform and were able to get up to only 8-9 km wireless range to mobile users on the ground with acceptable data rates.

The Marine Corps has defined operational needs in supporting its mobile users to move towards a network centric capability, however, they still are searching for the right platform to fulfill these needs. The following needs for the mobile users were provided by the MCWFL and have been broken down into specific technological requirements. They include:

- Coverage of a typical operational area – support for units up to the size of Naval Expeditionary Forces or Marine Expeditionary Forces.
- Continuous global assured access
- Secure voice/data comms to link small tactical units, including their command elements and fire support platforms up to a distance of 200 nm
- Bandwidth up to 9.6 kbps
- Netted communications capabilities
- Connectivity down to the squad level. For a deployed MEF, up to 40 voice/data nets with up to 300 tactical terminals per battalion.
- Mobile terminal sets weighing less than three pounds
- A minimum Look Elevation angle of 20 degrees for suburban and rural environments and 40 degrees for high-rise urban areas
- Secure capabilities to include LPI, LPD, and Anti Jam

- No dependency on ground infrastructure to close the links
- Minimal manning, logistics and support [MCW01]

Meeting these specifications alone will be a major task, but these requirements only comprise a portion of the total force that will likely be involved in major combat operation. The US Army will need similar support to some of these requirements. The MCWFL's current focus is on a space-based Low Earth Orbit (LEO) constellation and/or a Geostationary Orbit (GEO) constellation to fill these needs. In Chapter III of this thesis, the author's show why space systems can only partially support the stated Marine Corps needs.

2. Navy

The Navy and Marine Corps' combined vision for the 21st century are rooted in the *From the Sea* and *Forward… from the Sea* doctrine documents of the early 1990's. Emphasis has been placed on the littoral battlespace, supporting the full spectrum of conflict, providing global power projection, and having the capacity for interoperability in the joint and combined environment. Annual posture statements have re-emphasized the Navy's mission statements, but recently there has been a notable shift towards acknowledging the needs for integrating information superiority into all aspects of warfighting.

Recently, the Navy Warfare Development Command published *Network Centric Operations, A Capstone Concept for Naval Operations in the Information Age* to articulate the Navy's compliance with JV 2010 and JV 2020 concepts. This document underscores "the increasing importance of information as a source of power" [NCO01 p.1]. Each of the four pillars of Network Centric Operations (NCO) has applicability to this thesis. They are:

- Gaining the Information and knowledge advantage
- Assured access

- Effects-based operations
- Forward sea-based forces. [NCO01, p. 1]

The *Navy after Next* will rely on a tiered sensor architecture to gain battlespace knowledge. The bulk of the sensor data will continue to come from scarce national and theater assets, but a dense network of sensors will be needed to fulfill a wide range of requirements. Integrated sensor data will allow a shift toward less sophisticated weapons that draw precision from network centric operations. [NCO01]

To further illustrate the emergence of a Network Centric Force, the Naval War College has recently taken network centric operations as its focus. "The Naval War College conducted a Network Centric Warfare Symposium on August 14, 2001, kicking off the new academic year and exposing students to this year's theme of Network Centric Warfare." [Duh01]

3. Army

Army Vision 2010 is the follow on doctrine to the Army's Force XXI concepts and aligns its vision with the JV 2010 requirements. Army Vision 2010 clearly states a growing need for enhanced wireless communications and ISR platforms to fulfill its needs. To achieve Dominant Maneuver/Precision Engagement, the soldier of tomorrow will require a range of capabilities, to include:

- Sensor-to-Shooter Links
- Real Time Intelligence…. Vertical and Horizontal Distribution
- Information Dominance
- Battle Command on the Move. [DOA10, p. 14]

The Army Battle Command System (ABCS) bandwidth requirements for a single division currently stand at 5.1 Mbps. This figure does not account for either intelligence

or logistics support [ABC99]. If Army growth trends compare to the Navy's projections by 2006, 5.1 Mbps will exceed 17 Mbps. The Army acknowledges, "the transformation to the total Army will place additional narrowband requirements on its existing oversubscribed communications infrastructure." [NSC01] Future communications systems must support small hand-held, hands free or pocket-sized terminals for soldiers on the move. Emphasis will be placed on netted communication with a degree of low probability of intercept/low probability of detection (LPI/LPD).

4. Air Force

The Air Force Doctrine of the future is *Air Force Vision 2020,* which is consistent with JV 2010 and JV 2020 concepts. Of all of the services, the Air Force appears to have the least problems in transforming to a Network Centric Environment. Operating from land-based airfields has its advantages. The Air Force considers itself expeditionary, however, their basic infrastructure is not constantly on the move like the other services. Their demand for throughput, although large, is generally easier to achieve. Network connectivity is often obtained via direct fiber hookup or can be achieved with high capacity wideband fixed satellite systems. The Air Force still needs better support for its mobile users such as their tactical aircraft; however, their numbers are far less than the other services.

C. MILITARY BANDWIDTH REQUIREMENTS

1. Introduction

Before making a case for how HALE systems best fit into a communication architecture, an exploration is needed on current and future bandwidth requirements. Throughout the Department of Defense there have been numerous studies and many different projections on bandwidth needs. They all draw the same conclusion… the services are severely lacking, especially when considering support to large numbers of

users and surge operations. This demand will only increase as the force transitions to network centric operations.

2. Navy Bandwidth Needs

During Desert Storm, the Air Tasking Order (ATO) was published and distributed daily throughout the theatre of operation by air courier. The services did not have the communications infrastructure in place to send the ATO effectively or securely over any wireless medium. The Navy has made great strides in acquiring additional bandwidth since the Gulf War. A combination of military and commercial wideband systems have alleviated the immediate peacetime operational need. The difficulty it faces is using these systems to provide the projected throughput in surge operations such as a Major Regional Conflict (MRC) or when changes in doctrine require more bandwidth.

Figure 2.1 shows some historical and projected bandwidth data points for a single Naval Aircraft Carrier (CV). [NSC01] Note, a power function trend line was added to emphasize the fact that future requirements are difficult to predict and are often understated. This trend line is only a statistical calculation, a best match, based on observed growth patterns.

As of 2000, the typical CV was capable of exchanging data at about 3 Mbps. The sharp rise since the Gulf War can be attributed to Challenge Athena and military SHF wideband systems. As you can see, future projections increase dramatically as more onboard functions, once considered routine, become "mission essential". A large driver of future projections is the implementation of IT-21. Network Centric Operations promise to add more throughput requirements. As the Navy looks forwards to 2006, the following requirements drive its bandwidth demands:

- 3 Mbps for SIPRNET and NIPRNET
- 6 Mbps in DISN connectivity to support JWICS, DSN/phone, VTC, telemedicine, telemaintenance, and quality of life requirements.

- Over 11 Mbps for JSIPS (Primary Imagery Dissemination), non DISN VTC capability and an occasional requirement to link to the Predator UAV. [NSC01]

Keep in mind that these numbers are only for the CV. Neither the rest of the CV Battle Group nor additional bandwidth needs for network centric operations are factored into the totals.

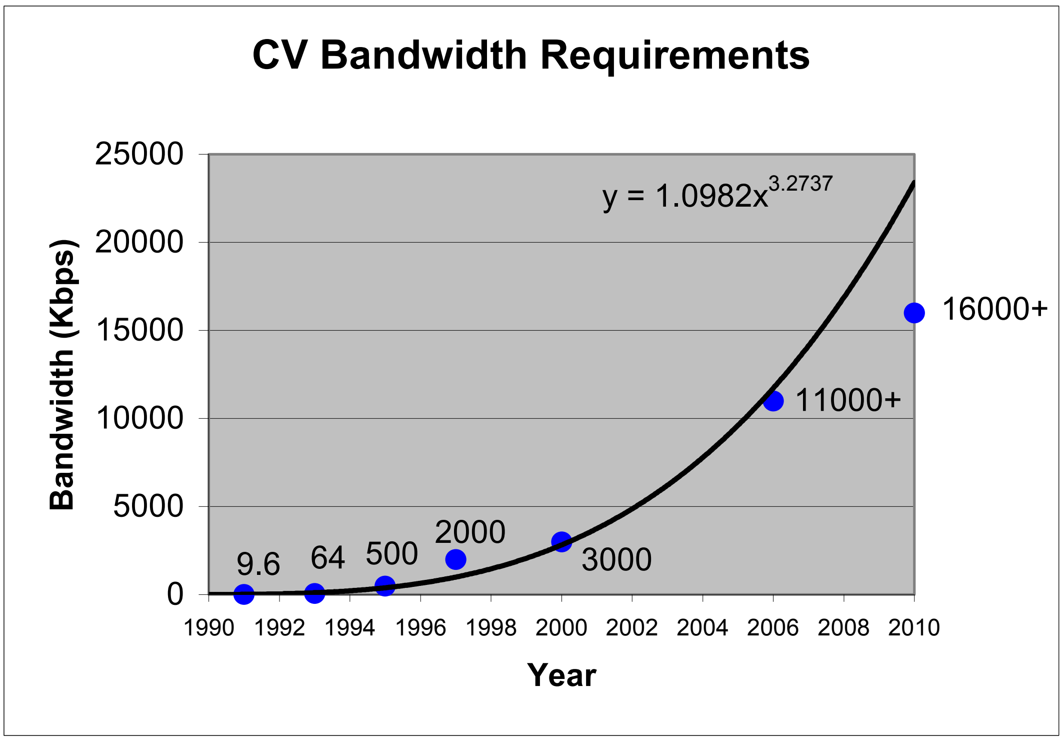

Table 1. Aircraft Carrier Bandwidth Requirements

3. Commercial Reliance

a) SATCOM

The services have successfully fulfilled some of their bandwidth shortfalls by leasing transponders on commercial SATCOM systems. The proliferation of commercial GEO and large LEO systems makes leasing an attractive alternative for DoD

planners, but concerns exist over assured access, availability, and suitability for wartime communications.

There are hundreds of communications satellites in Geostationary orbit and it would seem as though there would be an abundance of transponders to lease commercially, but this is not always the case. Satellite vendors do not typically launch their systems until they have sold 80% of their capacity. This practice helps ensure financial success. The additional 20% goes on the open market to the highest bidder. The Department of Defense is somewhat reluctant to contract for commercial SATCOM until systems are on orbit and operational. [NSC06] Therefore, there is a bidding process for the remaining scarce resources. Suffice it to say, US forces are not always successful in obtaining these resources. Recent operations in Kosovo provide a case in point.

Of the over 200 candidate GEO satellites, only three had transponder availability and accessibility to the Kosovo region. Of those three, two were Ku-band transponders, and one was a C-band transponder. In total, only 70 Mbps of bandwidth was commercially available, but the bandwidth need for the potential ground war was 200 Mbps [NSC06].

In the late 1990's, there was a good argument for leveraging large LEO commercial systems when it appeared that they would proliferate. Iridium is a perfect example of why the DoD cannot expect too much from novel commercial enterprises. Iridium's multi-billion dollars, 66-satellite constellation promised global reach to a selected portion of the wireless communications market. However, a poor business model and few subscribers left the company in financial ruin. The Navy has since signed a short term contracted for a good number of handsets and unlimited airtime, but is finding it difficult to integrate this capability into its overall communication network infrastructure. But obtaining resources is just one of DoD's problems with reliance on commercial systems.

Military commanders rely on assured access to communications in all phases of conflict. These "assurances" are often hard to obtain from commercial vendors. Many are members of international consortiums or have signed international agreements. The rights to these resources/transponders could be pulled because of political concerns

and/or conflicts of interest. Thus, reliance on commercial bandwidth can never be absolute. The Advanced Military SATCOM Capstone Requirements Document emphasizes the need for unique military systems

> "While it is clear and desired that DoD take full advantage (where affordable) of the commercial sector's capabilities and offerings, it must be recognized not all of the warfighter's communications needs can or should be met by commercial means, especially in an unpredictable threat environment." [USS98, p. 1-13]

b) ISR

There have been a number of commercial remote sensing satellite systems put on orbit by the US and other international and multi-national corporations that offer Electro optical (EO), Synthetic Aperture Radar (SAR), and Multi-spectral imagery. In terms of imagery resolution, they offer significant military intelligence potential. Systems like Ikonos can image at up to one-meter resolution, considered sufficient for targeting. However, problems with assured access and timely product delivery preclude these systems from fulfilling NRT warfighter needs. These corporations are in the business of providing services to the customer; however, one cannot reasonably expect these services to meet the stringent requirements of time critical military intelligence. Advanced contracting for these systems presents difficulties in determining what imagery needs will exist in future conflicts. Thus, commercial sensor support presents military users with difficulties in getting responsive operational support and continuous surveillance capabilities.

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III. CURRENT COMMUNICATIONS AND ISR SYSTEMS

A. INTRODUCTION

Before showing how HALE platforms can effectively integrate into wireless communications and ISR architectures, it is important to understand how well current systems support warfighters' needs and the shortfalls that exist. The authors first describe existing and planned Satellite Communications (SATCOM) platforms as they relate to providing support to the national military structure. Next, an unclassified analysis is conducted on the capabilities and deficiencies of ISR system operations from the following four regimes: GEO, MEO, LEO, and stratospheric.

B. COMMUNICATIONS

Wireless communications systems occupy a large portion of the EM spectrum and are classified in a number of different ways. In the scope of this thesis, they are categorized in three general areas: Mobile, Wideband, and Protected communications. This section covers SATCOM platforms in terms of the types of communication missions each support, and the deficiencies that remain. Table 3-1 depicts how the general categories relate, albeit roughly, to the Electromagnetic (EM) spectrum.

Category	Band	Frequency
Mobile	UHF	300 MHz – 3 GHz
Wideband	SHF	3 – 30 GHz
Protected	EHF	30 – 300 GHz

Table 2. SATCOM Category

1. Mobile Communications

Connecting mobile users into the network centric environment will prove to be toughest challenge. Mobile users require small, lightweight terminals with the capability

to operate through weather and foliage. Ultimately, users would like a cellular sized terminal with voice and data capability. This lightweight requirement and mobility typically means that warfighters need omni-directional antennas. The associated low power, low gain, and attenuation issues push the mobile warfighter primarily into the UHF spectrum. This UHF reliance reduces the amount of throughput, and ultimately, the number of users supported. Furthermore, the military UHF allocations of 225-400 MHz provide the lowest possible data transfer rates.

Mobile users are currently supported primarily via the UHF Follow-On (UFO) constellation. UFO is an eight spacecraft constellation with two satellites in each of the four worldwide coverage areas. The last of the UFO satellites, UFO-11, is slated for launch in December 2003. Though this system gives worldwide, ubiquitous coverage, it is lacking in several important areas. Foremost, UFO provides limited availability. The number of channels the system can support is limited by spectrum allocation. Currently, the system is oversubscribed by about 250% and cannot meet the user's needs in terms of capacity, comms-on-the-move, and network control [Nic01]. Another limitation involves communications requirements for urban areas. The Marine Corps has a defined look angle requirement of 40° for urban operations. However, from geostationary orbit, a 40° look angle is not possible above 43.5° North and below 43.5° South latitudes. This restriction would exclude, for example, all of Europe north of Italy.

A number of studies, such as the Mobile User Study (MUS), were conducted to analyze potential solutions to the mobile problem. The proposed solution is the Mobile User Objective System (MUOS). This proposal is a multi-faceted system encompassing terrestrial and space assets.

On the terrestrial side, the MUOS Operational Requirements Document (ORD) lists a number of solutions, to include, Airborne Communications Nodes aboard UAV's, Aerostats, and manned aircraft. It discusses, at length, the performance requirements but not specific platforms to be utilized. [MUO00, p.2]

On the space side, the MUOS plan calls for a six-satellite GEO constellation with the first launch targeted for 2007. However, the Navy led MUOS program office is considering delaying the initial MUOS launch in favor of extending the current run of

UFO satellites through UFO-12 and UFO-13. MUOS's projected cost is 3-4 billion dollars and the hope is to have them operational for more than 10 years. MUOS, like UFO, is slated to operate in the military UHF band, which will limit its capacity. [Wal01]

2. Wideband Communications

a) Introduction

Military and commercial Super High Frequency (SHF) wideband communications systems provide the warfighter with large throughput and global reach back capabilities. Wideband systems carry the majority of intelligence, imagery, VTC, and Defense Information Systems Network (DISN) traffic. These systems are typically "bent pipe" versus processed, meaning the satellite simply receives, translates, amplifies and retransmits the signal to the ground terminal. Complexity of such systems is placed on the groundside vice the space segment. Ground stations transmit high power signals via large, high gain antennas. Users must be capable of supporting these large antenna configurations.

Currently, the warfighter relies on a combination of government and commercial SHF satellite assets. The Defense Satellite Communications System (DSCS) III program is the mainstay of the SHF wideband communications capability. The Global Broadcast System (GBS) was launched aboard UFO satellites to increase wideband capabilities via a "broadcast" service. Challenge Athena (CA) is the Navy's most successful wideband commercial venture. Terminal fielding began onboard USS George Washington in 1992. The current system, Challenge Athena III is being fielded on all CV/CVNs, and proliferation has begun to AGFs, LCCs, LHAs and LHDs [NSC03].

Shortfalls in existing wideband capabilities include; support to disadvantaged users, comms-on-the-move, interoperability, and protection. Future systems include the Interim Wideband System, to be followed by the Advanced Wideband System.

b) Interim Wideband System (IWS)

The three components of the IWS are the Wideband Gapfiller System (WGS), DSCS III, and GBS.

(1) Wideband Gapfiller System - The Wideband Gapfiller System (WGS) vision is to support the tactical warfighter via a constellation of three GEO satellites. Deployment of the system is to begin in 2004, and should reach full operational capability by 2005. The goal of the satellite's design is to fully leverage commercial technology, to include, higher power transponders and more efficient bandwidth modulation techniques. WGS key performance parameters include the following threshold requirements:

- 1.2 Gbps minimum throughput
- Fully interoperable with current DSCS III and GBS systems
- Life cycle costs not to exceed $1.181 billion. [NSC04]

WGS shortfalls include, support to the disadvantaged user, comms-on-the-move, anti-jamming protection, and flexibility.

(2) DSCS III - The current DSCS III constellation is made up of five primary satellites and five residual systems. The residual satellites provide backup services in the event a primary satellite fails. Worldwide coverage is achieved through the placement of satellites in five geosynchronous orbital slots. The DSCS program supports a diverse mix of users, providing intelligence information, DISN services, and support to the tactical warfighter. The current DSCS satellite improvement plan is called the DSCS III Service Life Enhancement Program (SLEP). Under this program, the DSCS III satellites have received more powerful amplifiers in all channels, improved low noise amplifiers, and an addition channel with access to the gimbal dish antenna. These enhancements support the warfighter by increasing capacity and coverage, especially to small, disadvantaged terminal users. The shortfalls of the DSCS III and DSCS III SLEP are protected communication, comms-on-the-move, and flexibility.

(3) Global Broadcast System (GBS) - The Global Broadcast Systems was conceived to better serve the warfighter by providing rapid data dissemination via large capacity K-band satellite transmitters. Using commercial Direct TV-like technology, GBS provides broadcast only data at rates up to 23 Mbps [NSC04]. Three satellites have been launched, but terminal fielding has been slow due to funding issues. The strength and weakness of the GBS is its broadcast only capability. At the time of its conception, throughput via any means was the priority; however, this decision does not fit well into the network centric vision of the future. Broadcast services, by design, have numerous shortfalls, including poor bandwidth efficiency, interoperability, flexibility, and protection.

c) Advanced Wideband System (AWS)

The Joint Requirements Oversight Council (JROC) approved a wideband roadmap that includes the procurement of an entirely new constellation of wideband GEO satellites in the 2008 timeframe. The AWS is to leverage off WGS best practices and emerging commercial technology. [NSC03]

3. Protected Communications

a) Introduction

Protected communications are a unique military requirement. These systems must be nuclear hardened, resistant to physical destruction and jamming, and have defensive information operations capabilities. Additionally, protected systems employ low probability of intercept/detection (LPI/LPD) techniques to maintain covertness. Future military doctrines promote the use of protected systems to ensure information dominance. Current protected communications systems include three Milstar Satellite Communications System, two Fleet Satellite (FLTSAT) EHF Package (FEP),

three UFO/EHF Package (UFO/E), four Enhanced UFO/E Package (UFO/EE), and one Interim Polar EHF System satellites. [NSC05]

b) Milstar Satellite Communications System

Milstar is a joint service protected satellite communications system. It represents a "leap" in U.S. communications capability, serving as a "smart switchboard in space." [MSC99] The first two Milstar satellites were only capable of a low data rate (LDR) mode of operation (75 bps to 2400 bps). The first of four planned Milstar 2 medium data rate (MDR) capable (4.8 kbps to 1.544 Mbps) satellites was placed in a useless orbit by a Titan IV-B upper stage Centaur rocket motor in April 1999. One of the remaining three MDR Milstar 2 satellites was launched in February 2001. [NSC05]

Milstar satellites can link to one another using a W-band frequency crosslink. A fully operational constellation of Milstar satellites would allow worldwide EHF connectivity without the use of any ground relays.

The major shortfall of Milstar is its low throughput and interoperability. By design, "most of the EHF MILSATCOM bandwidth is used to support the protected waveform (spread spectrum and symbol repetition)." [NSC05] Custom EHF terminals must actually log onto the satellite network.

c) Advanced EHF (AEHF)

The future Advanced EHF communications satellite system is scheduled to replace Milstar beginning in December 2005. A fully operational AEHF constellation would consist of four fully crosslinked satellites providing worldwide coverage. The system promises to greatly increase capacity to the warfighter while maintaining Milstar-like protection capacities. Changing requirements have already led to cost increases and schedule delays in the program. The original cost of $2.5 billion is now estimated at $4.3 billion, according to an Air Force spokesperson. [Tut01]

C. ISR SYSTEMS

The current ISR system infrastructure is a system-of-systems spanning from terrestrial to space regimes. This section shows the general capabilities and deficiencies that current platforms in the US ISR architecture provide to the warfighter. This information is provided in generic terms relating ISR mission requirements to performance characteristics from four operating regimes: Geostationary Orbit (GEO), Medium Earth Orbit (MEO), Low Earth Orbit (LEO), and stratospheric stations. The Highly Elliptical Orbit (HEO), or Molniya, regime has been omitted due to its similarity to GEO. HEO provides polar coverage at apogee altitudes near GEO, and therefore shares similar long dwell (although not continuous) and coverage characteristics. Specific ISR systems capabilities and shortfalls will not be discussed due to their classified nature. The data provided in this section lays the analytical foundation for the next chapter that details HALE advantages in these critical mission areas.

Three ISR mission categories are covered in this section, encompassing a broad range of ISR missions conducted to support operational requirements. The general mission categories are; Electro-optical (EO) imaging, Synthetic Aperture Radar (SAR) imaging, and Signals Intelligence (SIGINT) related collection capabilities. It will become clear in the following tables where these systems leave gaps in providing capable and continuous ISR support.

1. Electro-optical

Electro-optical (EO) imaging instruments are passive sensors that typically detect EM radiation in the visible and Infrared (IR) spectrum. EO systems provide day/night capabilities for general intelligence, targeting, and Battle Damage Assessment (BDA). Support for these critical mission areas is dependent on the following essential EO characteristics: resolution, dwell time, access, and instantaneous area access.

The resolution of an optical system is defined as its ability to distinguish fine detail [Wer99, p. 263]. The variables that determine resolution are the operating wavelength, the altitude of the sensor, and the diameter of the sensor's aperture. Visible sensors have better spatial resolution due to shorter wavelengths (.4-.9 μm) as compared to IR detectors operating at wavelengths of 1-100 μm. Equation 1 shows the relationship between the variables in determining resolution [Wer99, p. 264].

$$X' = \frac{2.44 h \lambda}{D}$$

Where X' = Ground resolution at nadir Eqn. 1
h = Satellite altitude
λ = Wavelength
D = Aperture diameter

The following measures are used for the comparative analysis found in Table 3:

Resolution: High – Target Quality Images
Med – Local Area Coverage
Low – Wide Area Coverage

Dwell is the period of time the sensor maintains view of the object or target. In general, the longer the dwell time, the better the operational support to the user. Longer dwell allows for video surveillance and enhanced targeting and BDA support. The following criteria are used throughout this section:

Dwell Time: High – Continuous or NRT coverage
Med – Greater than 15 minutes but less than Continuous
Low – Less than 15 minutes

Access area is defined as "the total area on the ground that could potentially be seen at any moment." [Wer99, p. 263] As a satellite orbits, or an aircraft flies through the

atmosphere, sensors are able to gain access to various portions of the Earth's surface. This accumulated coverage area can be global or constrained to regional or local areas, as determined by orbital inclination and altitude. Further restrictions are placed on airborne or stratospheric platforms due to international airspace boundaries. Access for a single platform is defined as:

Access:

Global –	Pole to Pole
Worldwide –	65° N to 65° S
Local –	Within theatre of operations

Instantaneous access area (IAA) is defined as "all the area that the instrument or antenna could potentially see at any instant if it were scanned through its normal range of orientations." [Wer99, pg. 164] The limiting factor is the horizon, thus the higher the altitude, the larger the access area. For the analysis in Table 3 through 5, IAA is given for a range of look elevation angles from 0° (horizon) to 30°. Look elevation is an angular measurement, made from the observer's local horizon to the satellite, aircraft, or HALE platform. The look elevation angle is determined by the warfighter's need

The following altitudes have been used for comparative analysis purposes: GEO is defined as 35,786 km, MEO 20,184 km, LEO 700 km, and HALE 21.33 km (70,000 ft).

Table 3 shows the comparative capabilities of the stations studied.

Regime	**Resolution**	**Dwell**	**Access**	**IAA (nm^2) for 0-30°**
GEO	Low	High	Worldwide	63,249,000 – 29,128,000
MEO	Low	Med	Global*	56,628,000 – 24,655,000
LEO	High	Low	Global*	7,370,000 – 858,000
Stratosphere	High	High	Local	248,000 – 1,230

Table 3. EO Regime Comparison

* Requires a highly inclined orbit

2. Synthetic Aperture Radar

Synthetic Aperture Radar (SAR) imaging systems are day/night, all weather capable. They use platform motion (satellite or aircraft) to synthetically produce an aperture length of sufficient size to obtain a specific image resolution. Equation 2 is used to calculate azimuth (cross range) resolution distance for a synthetic array [STI98, pg. 424]. However, a theoretical minimum cross range resolution exists for a focused SAR system. That minimum value is D/2, where D equals the real/physical antenna width. One can defeat this minimum by using a Spot Mode technique, and thus obtain the resolution expressed in Equation 2 with proper processing algorithms.

$$d_a = \frac{\lambda R}{2L}$$

Where λ = Wavelength   Eqn. 2

L = Array length

R = range

As evident from Equation 3, the effective antenna length is a function of radar motion. In order to obtain an image in a reasonable amount of time, a sufficiently fast platform is required. Problems associated with long exposure time include frequency coherency and motion within the frame. SAR images are computationally more difficult to process and harder to interpret than EO/IR images.

$$L_{eff} = vt$$

Where L_{eff} = Effective antenna length   Eqn. 3

v = Velocity of the radar platform

t = Integration time

For the following capabilities comparison, the same orbit parameters and measures of effectiveness are use as those on the EO chart.

Regime	Resolution	Dwell	Access	IAA (nm^2) for 0-30°
GEO	None	High	Worldwide	63,249,000 – 29,128,000
MEO	Low	Med	Global*	56,628,000 – 24,655,000
LEO	High	Low	Global*	7,370,000 – 858,000
Stratosphere	High	High	Local	248,000 – 1,230

Table 4. SAR Regime Comparison

3. SIGINT Related Missions

This comparative analysis covers the rest of the ISR missions, to include: Signal Intelligence (SIGINT), Measurement and Signatures Intelligence (MASINT), and other INT's systems. Although traditionally considered strategic, these missions are increasingly gaining tactical relevancy. The goal of the collection platform is to position itself "in view" of the target emission, and be close enough to the source to "sense" the data. The ideal collection system has long dwell, continuous global access, geo-location capabilities, and sufficient sensing ability to detect the specific signal/signature of interest.

For the comparative analysis of this mission area, the same orbital parameters are used as with EO and SAR. However, for the measures of effectiveness, instead of resolution, a sensor's signal strength rating is included. In terms of signal strength, the closer the emission is to the collector, the easier it is to sense. This is primarily due to free space path loss, discussed in detail in Chapter IV.

* Requires a highly inclined orbit

Regime	Signal Strength	Dwell	Access	IAA (nm^2) for 0-30°
GEO	Low	High	Worldwide	63,249,000 – 29,128,000
MEO	Medium	Med	Global*	56,628,000 – 24,655,000
LEO	High	Low	Global*	7,370,000 – 858,000
Stratosphere	High	High	Local	248,000 – 1,230

Table 5. SIGINT Regime Comparison

* Requires a highly inclined orbit

IV. STRATOSPHERIC CONSIDERATIONS

A. INTRODUCTION

The essential considerations for operating in the stratosphere are analyzed in this chapter. It is important to understand the technical areas where the stratosphere provides both enhancements and adequate alternatives to space-based systems. The chapter has been formatted into four sections; 1) an overview of the stratospheric environment, 2) a discussion of the general technical issues affecting both communication and ISR employment 3) a look at specific communications and wireless network related issues, and 4) an analysis of specific ISR issues.

B. STRATOSPHERIC ENVIRONMENT

The stratosphere is the upper layer of the atmosphere that extends from roughly 8 to 12 miles at the lower end to the upper edge at about 30 miles. This equates to about 39,500 ft to nearly 152,000 ft. The regime of primary concern for HALE platforms is the altitude below 100,000 ft where the upper reaches of our HALE craft operate. The air temperature in the stratosphere remains relatively constant up to an altitude of about 16 miles, and then increases gradually. This increase with altitude does not cause significant convection and thus has a stabilizing effect on atmospheric conditions in the region. Ozone plays the major role in regulating the thermal regime of the stratosphere, and water vapor content within the layer is very low.

The lack of water vapor prevents cloud formation, therefore rain and icing is not a concern. Winds are the only significant weather issue. But, stratospheric winds are relatively benign compared to those in the troposphere, especially near the tropics and within defined boundary layers. The most stable layers appear to exist around 70,000 and 90,000 ft altitude. Mean wind speeds of 0-70 kts are typical at these altitudes, within +/-40° latitude of the equator. Additionally, stable temperature and low winds result in light turbulence in the stratospheric environment.

C. STRATOSPHERIC TECHNICAL ISSUES

A HALE platform cannot provide the same amount of wide area coverage as satellite systems, but to what extent does their coverage fall short? In terms of link margin, how well will GEO systems support large numbers of small terminals?

The following issues affect both communication and ISR operations. The analysis in this section shows that stratospheric altitudes can provide sufficient coverage and greatly increased link margin to better support communications and ISR operations in the theatre of operations.

1. Coverage

Though HALE systems have smaller coverage areas, they do have the capacity to monitor an entire area of operations from a JTF commander's perspective. The maximum radius of coverage is determined by the platform's altitude and the required look elevation angle. The look elevation angle is measured from the local horizon of the observer to the satellite or HALE platform.

The look elevation angle is determined by the warfighter's need. For example, communications in an urban environment may have a 30-40° requirement, an imagery system may not be capable of looking less than 20°, but a SIGINT system may be capable of supporting the warfighter out to the platforms line of sight limit (0°). Figure 1 shows maximum radius calculations for all HALE altitudes at different look elevation angles.

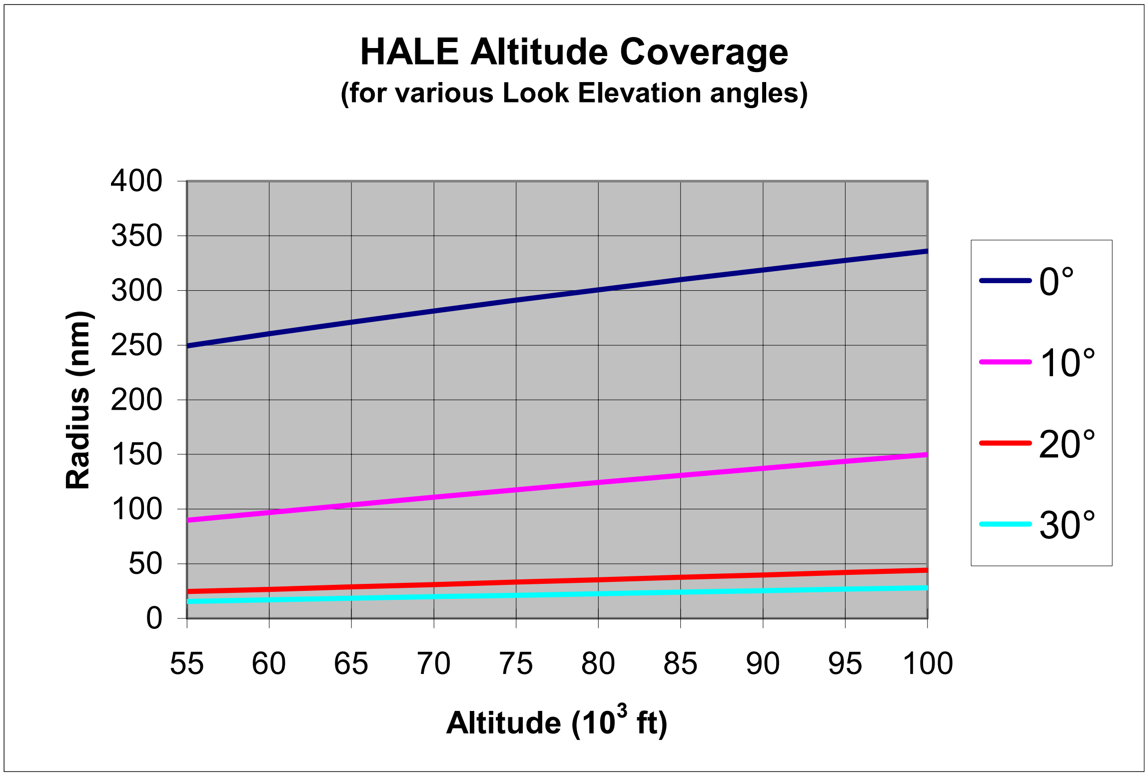

Figure 1. HALE Altitude Coverage

Another important measure of a systems ability to provide coverage of an area is Instantaneous Access Area (IAA). IAA is defined as "all the area that the instrument or antenna could potentially see at any instant if it were scanned through its normal range of orientations." [Wer99, pg. 164] Equation 4-1 shows a simple formula for the calculation of IAA.

$$IAA = K_A(1 - \cos\varepsilon)$$

Where ε = Look elevation angle

K_A = 7.45222569 x 10^7 for area in nmi^2

Eqn 4

As with the maximum radius coverage calculations, IAA calculations are presented for HALE altitudes at various look elevation angle increments (see Figure 2 and 3).

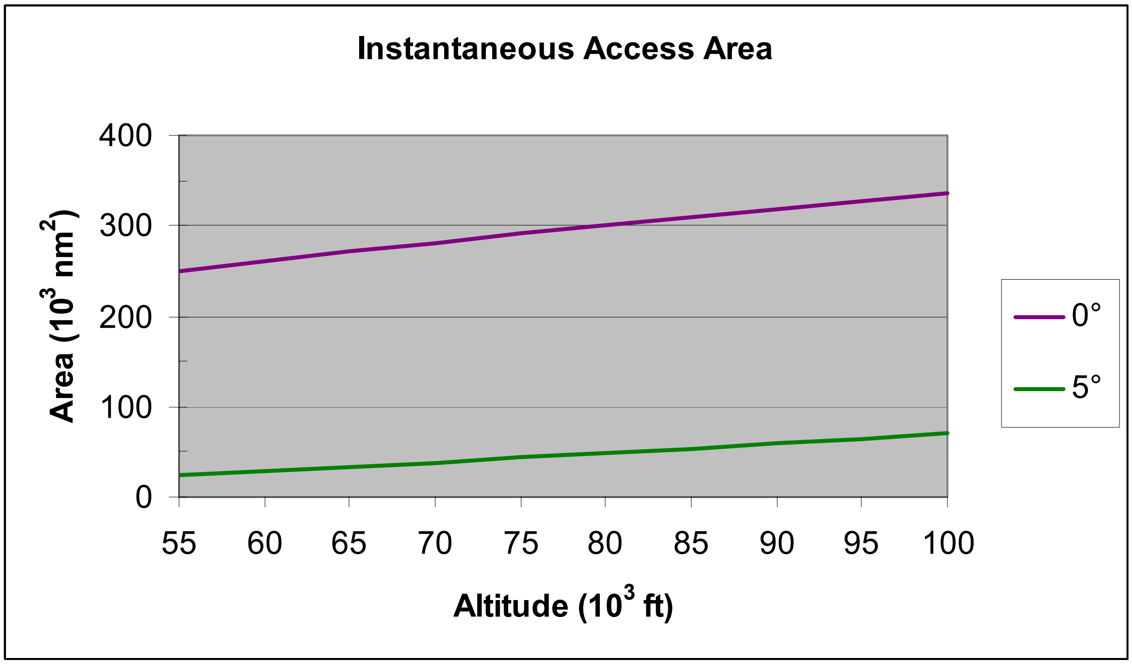

Figure 2. Instantaneous Access Area (0-5° Look Elevation angles)

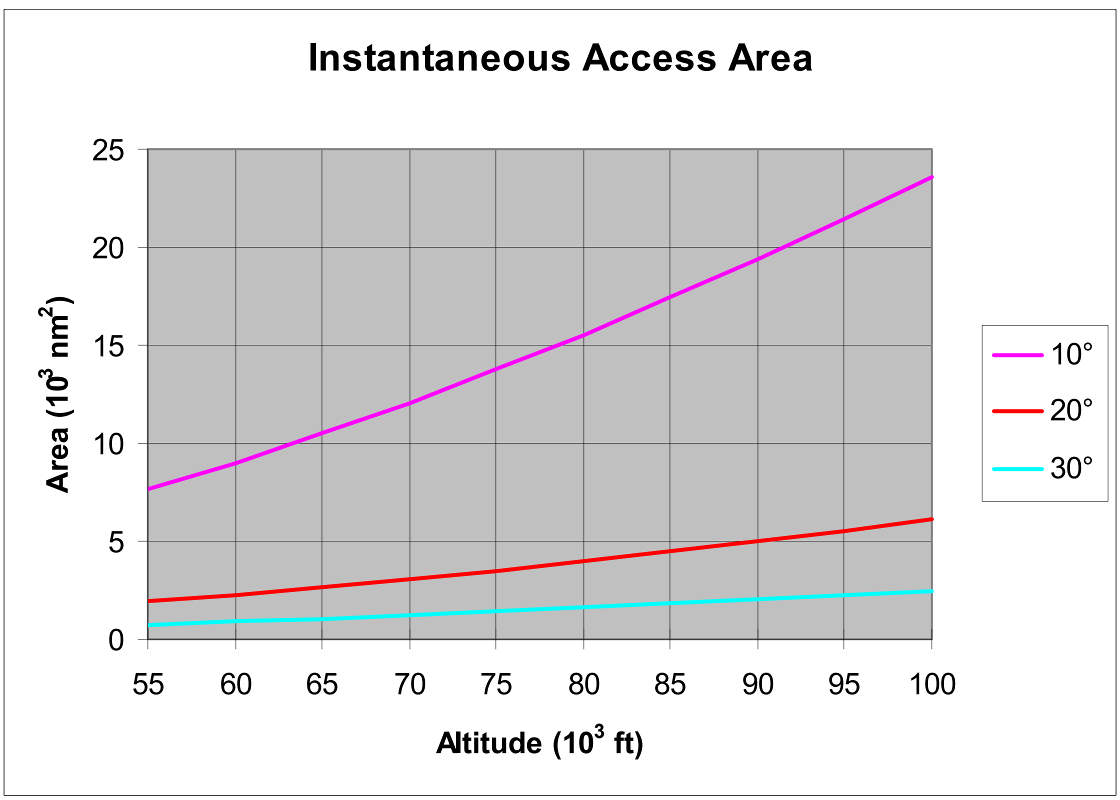

Figure 3. Instantaneous Access Area (10-30° Look Elevation angles)

To get a truer sense of the extent of HALE platform coverage, the reader may wish to turn to Chapter VII, Concept of Operations, for a more graphical depiction.

2. Link Budget

The following calculations give a comparative analysis between HALE and space-based platforms in the area of link requirements for communication needs. A key to communications engineering is the necessity of closing the link between transmitter and receiver, while providing a sufficient degree of margin. The same holds for SIGINT systems, except the collection system design is the only variable. This area offers perhaps the greatest advantage for stratospheric systems over space-based assets. Greater link margins enable a number of specific warfighter needs:

- Smaller and lower power man-portable terminals
- Low Probability of Intercept/Low Probability of Detection (LPI/LPD) communications
- Reduced electro-magnetic interference (EMI)
- Greater sensor sensitivity - to detect and locate low power emissions

Numerous characteristics determine the ability of a system to close the link. Transmitter gain, antenna gain, and receiver gain are designed to overcome atmospheric attenuation and free space path loss. Free space loss is the single largest driver of satellite communications links. The spreading of the transmitted beam, and thus the power, over a wider area as it travels great distances results in significant loss. From Equation 5 and 6 one can see that the intensity of the signal is inversely proportional to the square of the distance from the transmitter to the receiving antenna, and is wavelength dependent.

$$L_s = \left(\frac{\lambda}{4\pi R} \right)^2$$

Eqn. 5

Where λ = Wavelength

R = Distance between the transmitter and receiver

Or

$$L_s = \left(\frac{c}{4\pi R f} \right)^2$$

Eqn. 6

Where c = Speed of transmission (speed of light assumed)

f = Frequency

Finding the distance between the transmitter and receiver requires a few additional steps. Figure 4 identifies all the factors needed to calculate the maximum range based on a given look elevation angle. Intermediate steps include calculating both the nadir angle (Eqn. 7) and Earth's central angle (Eqn. 8). Equation 9 is the maximum range (R_{max}) formula.

$$\sin\eta = \left(\frac{R_e}{R_e + H} \right) \bullet \cos\varepsilon \qquad \text{Eqn. 7}$$

$$90^\circ = (\lambda + \eta + \varepsilon) \qquad \text{Eqn. 8}$$

$$R_{\max} = \left(\frac{\sin\lambda}{\cos\varepsilon} \right) \bullet (R_e + H) \qquad \text{Eqn. 9}$$

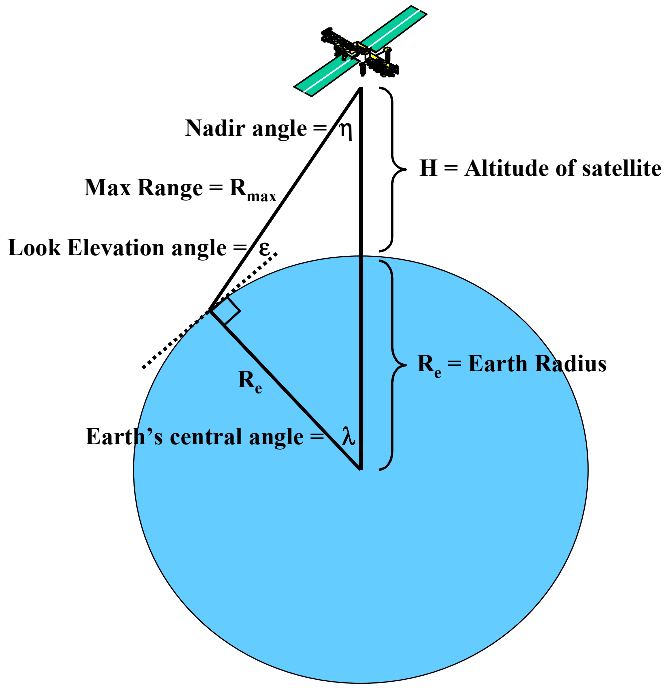

Figure 4. Look Elevation Angle

Maximum range and free space loss example: Consider a Geosynchronous satellite, transmitting a UHF signal at a frequency of 300MHz. The observer on the ground requires a minimum Look Elevation angle of 10°.

Given: $H = 35{,}786$ km
$R_e = 6378$ km
$f = 3.0 \times 10^8$ Hz
$c = 3.0 \times 10^8$ m/s
$\varepsilon = 10°$

To find R_{max}, first calculate the satellite's Nadir angle (η).

$$\eta = \sin^{-1}\left[\left(\frac{6378}{6378+35786}\right)\bullet\cos 10^\circ\right] = 8.57^\circ$$

Some simple geometry results in the calculation of the Earth's Central angle (λ).

$$\lambda = 90^{\circ} - 8.57^{\circ} - 10^{\circ} = 71.43^{\circ}$$

R_{max} follows.

$$R_{\max} = \left[\left(\frac{\sin 71.43^{\circ}}{\cos 10^{\circ}} \right) \bullet (6378 + 35,786) \right] = 40,586km$$

Next Free Space Loss (L_s) is calculated - this result is typically expressed in decibels.

$$L_s\,(db) = 20 \bullet \log \left(\frac{3x10^8}{4 \bullet \pi \bullet 40.586x10^6 \bullet 3x10^8} \right) = -174.15db$$

Similarly, values for HALE, LEO, and MEO altitudes were calculated. Table 6 shows the results of the Free Space loss comparison for a 300MHz UHF signal. Note the free space path loss difference for a GEO satellite at an altitude of 35,786km compared to a HALE platform at an altitude of 65,000ft. A 51.43db difference in signal strength would exist due to the Free Space loss affect. This equates to a factor of more than 100,000.

$$10^{\left(\frac{51.43}{10}\right)} \cong 139,026$$

In summary, given the same transmit out power and antenna gain; the GEO satellite signal would arrive over 100,000 times weaker at the Earth's surface. An even greater concern is signal transmission in the other direction, from the low power ground terminal to the satellite.

Altitude		Maximum Range at 10° Look-Elevation Angle	Free Space Path Loss
65000ft	19.8km	108.85km	-122.72db
95000ft	28.9km	155.8km	-125.84db
LEO	700km	2155.3km	-148.65db
MEO	20184km	24701km	-169.84db
GEO	35786km	40586km	-174.15db

Table 6. Free Space Path Loss

D. COMMUNICATIONS/NETWORK ISSUES

The following technical issues are provided to analyze the stratospheric capabilities that relate only to the communications/ network implications.

1. Bandwidth Capacity

Essentially, higher frequency bands enable an increased capacity to transfer data. This issue becomes paramount as the transition to the network centric environment takes place and attempts are made to move even larger amounts of data. The Shannon Limit (Eqn. 10) formula is used to compute information capacity or throughput. It determines the maximum data transfer rate based on the available bandwidth. It is a linear function if the same percentage of the bandwidth is utilized.

$$I = 3.32\, B \log_{10}\left(1 + \frac{S}{N}\right)$$

Where I = Information Capacity — Eqn. 10

B = Bandwidth

S/N = Signal to noise ratio

Table 7 shows the maximum possible data rates, according to the Shannon limit, for current military communications systems. Data rates are based on a S/N of 1000 (30

db), which was simply used to demonstrate the relative performance between various frequencies. The available bandwidth used for each calculation is 10% of the frequency.

Frequency	Bandwidth (10%) of Freq	Comms System	Band ID	Data Rates (Shannon Limit)
138-144 MHz	13.8-14.4 MHz	Air/Grnd Radios	VHF	138-143 Mbps
225-400 MHz	22.5-40 MHz	AF/FLT SATCOM, UFO	Mil UHF	224-399 Mbps
1.575 GHz	157.5 MHz	GPS L1	L Band	1.57 Gbps
2.2-2.9 GHz	220-290 MHz	Space-Ground Link System (SGLS)	S Band	2.19-2.89 Gbps
7.9-8.4 GHz	790-840 MHz	DSCS (UpL)	Mil X Band	7.87-8.37 Gbps
20.2-21.2 GHz	2.02-2.12 GHz	GBS (DnL)	K Band	20.1-21.1 Gbps
30-31 GHz	3-3.1 GHz	GBS (UpL)	Ka Band	29.9-30.9 Gbps
43-45 GHz	4.3-4.5 GHz	MILSTAR (UpL)	V Band	42.8-44.8 Gbps

Table 7. Military Communications Systems Theoretical Data Rate Limits

The essence of this section is that it will benefit the warfighter to utilize higher frequencies to increase throughput. As was described in the link budget section, higher frequency use requires more power due to greater attenuation and losses, again limiting the mobile users. HALE based systems offer the shortest distance, mitigating this higher power requirement and enabling higher band usage.

2. Frequency Reuse

Frequency allocation is a major concern for both military and commercial users. In order to prevent EMI problems, the federal communications commission (FCC) assigns the frequency bands in the US while the International Telecommunications Union (ITU) does this on the world scene. The military UHF spectrum (225-400 MHz), for example, is a very limited resource. This resource is shared by chopping up the frequency into narrow channels, either 5 or 25 kHz wide, or employing frequency management schemes like Demand Assigned Multiple Access (DAMA) where the bandwidth is dynamically assigned on an as needed basis. Through these methods support is provided to a wider number of users in a geographical region, but at the cost of reduced throughput to any individual user.

Frequency reuse issues are particularly significant with UHF frequencies because omni directional antennas are most often used vice focused beams. Therefore, mutual or unintentional interference is more prevalent if users are not spaced far enough apart geographically. The first method of frequency reuse is “allocating the same frequency to more than one cell” [Tom88, pg. 286]. In effect, this is done; except GEO satellites form huge cells and very little worldwide reuse is achieved. Recall, only four geographical regions are supported via the UFO constellation. Since adjacent cells cannot reuse the same frequency, the UHF spectrum is reused only twice. HALE systems have smaller, more concentrated footprints capable of much greater frequency reuse if configured in the manner of a terrestrial cellular system. The second method of reuse is via orthogonal polarizations of the transmitted signal. Here the same frequency carrier is transmitted twice, once by way of horizontal linear polarization, the other via vertical polarization. The receiving terminal perceives only the matched polarized signal, ignoring the signal 90° out of phase.

One issue that is beyond the realm of this research but might enhance the use of wider bands in the EM spectrum is the issue of frequency allocation. From a satellite designer’s standpoint, communications systems must operate in the allocated band for legal and interference reasons. Growth potential is restricted in this allocated band. The cellular tower concept of frequency reuse from space is limited, though not impossible, because of the larger footprints involved. HALE platforms, on the other hand, have more flexibility. First, it might be possible to use other bands on a not-to-interfere basis, because the lower power requirements will lessen the potential for interference. Secondly, the smaller footprints will facilitate the cellular tower type frequency reuse architecture.

3. LPI/LPD

There is a defined need from tactical warfighters to have communication systems that will not be easily detected or intercepted by hostile forces. One method to alleviate the LPI/LPD problem is to reduce the transmitter power. The close proximity of HALE

systems to the theatre of operations makes it uniquely suited to allow low power transmitters that can satisfy the link margin requirements. With more link margin to play with, HALE platforms could migrate to higher frequencies, enabling higher data rates, which would allow for shorter duration, burst transmissions that are harder to detect. Another means by which HALE craft could achieve LPI/LPD is via smaller spot beams for a given antenna size.

4. Jamming

It is a general concession that the U.S. military reliance on space systems could well be its Achilles Heel. Therefore, jamming is a significant concern in a combat environment. Space-based UHF assets have footprints that cover an entire theatre of operations. If an adversary could successful jam the uplink frequency of one of these satellites, UHF coverage to the entire region could be disrupted, severely affecting support to widely dispersed warfighters.

Extremely High Frequency (EHF) and SHF space-based transmissions are typically more directional, projecting smaller footprints. Additionally, many of these systems have anti-jam capabilities like the ability to null sectors from which jamming is originating. These active SATCOM cells do not, however, have enough accuracy to be placed at the forward line of troops (FLOT) without the potential for overlapping an adversary's front lines. These deficiencies will provide the capability for hostile forces to jam the uplinks inside this overlap.

In contrast, the close proximity of HALE platforms gives it a more natural insulation to jamming in all bands. They have smaller footprints and the added link margin to support higher frequencies that can provide more precise directional beam control than space-based systems.

E. ISR ISSUES

Besides the general coverage issues and link budget concerns for ISR systems, resolution and near real-time support are addressed to analyze those issues that relate only to ISR missions.

1. Resolution

a) Electro-optical

As noted earlier, resolution is the ability to distinguish fine detail and Equation 1 is the formula used to calculate ground resolution for an EO or IR sensor. Figure 5 provides a comparison of HALE resolutions for imaging a visible signature (.5 μm) using a 10 cm (3.9 in) diameter lens.

$$X' = \frac{2.44h\lambda}{D}$$

Where X' = Ground resolution at nadir
h = Satellite altitude
λ = Wavelength
D = Aperture diameter

A GEO imagery satellite is capable of providing continuous access to one-third of the Earth's surface, but resolution capabilities fall short of having military significance. Similarly, a MEO system provides global access and adequate dwell time; however, resolution is poor using modern EO techniques. LEO systems on the other hand can provide target quality imagery and global access; however, dwell time is on the order of minutes and revisit time over the same area can take days.

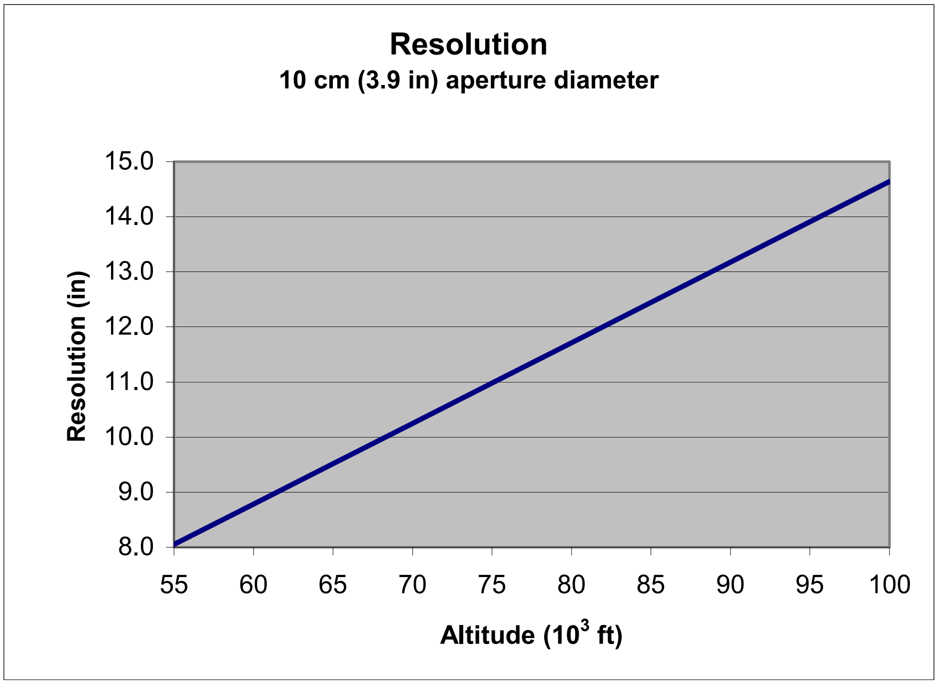

Figure 5. HALE Resolution

Space Imaging's Ikonos commercial imagery satellite provides an excellent example of the advantages and disadvantages of a LEO remote sensing system. Ikonos is in a highly inclined, sun synchronous, circular orbit at an altitude of 680 km. From this orbit, the satellite achieves global coverage and resolution on the order of 1-meter. However, dwell time is less than 15 minutes per access, insufficient for future requirements of continuous near real-time (NRT) capabilities. Ikonos' revisit time to a target at 40° latitude is 2.9 days if the requirement is for a near nadir 1-meter resolution image. For a less constraining 1.5-meter resolution image, it would still take 1.5 days to return to the target area. [Ols00, p. 78-79] In providing the required sensor-to-shooter support, numerous expensive Ikonos type sensors would be necessary to maintain near continuous coverage of a theatre of operations.

A comparison of LEO and HALE imaging resolution capabilities highlights the technical complexity involved in space-based imaging. From Equation 1, the nadir distance (h) from the satellite/platform to the Earth's surface is proportional to the diameter (D) of the optics for a given resolution and wavelength. Therefore,

comparing Ikonos at nearly 700 km to Global Hawk flying at 65,000 ft (19.812 km) results in the need for a lens 35 times larger to achieve the same ground separation distance.

$$\frac{D_{LEO}}{D_{HALE}} = \frac{h_{LEO}}{h_{HALE}} = \frac{700,000}{19,812} = 35.33$$

b) Synthetic Aperture Radar

Synthetic Aperture Radar (SAR) imaging systems use platform motion (satellite or aircraft) to synthetically produce an aperture length of sufficient size to obtain a specific image resolution. Recall, Equation 2 is used to calculate azimuth resolution and Equation 3 determines the effective antenna array length. [STI98, p. 424].

$$\mathrm{d_a} = \frac{\lambda R}{2L}$$

Where λ = Wavelength
L = Array length
R = range

$$L_{eff} = vt$$

Where L_{eff} = Effective antenna length
v = Velocity of the radar platform
t = Integration time

LEO is currently the only viable satellite orbit for SAR imaging systems. At a velocity of approximately 7.5 m/s, a C-band SAR system typically needs several seconds, if not tens of seconds, to produce an effective aperture length long enough to generate a 1-meter resolution image. This is evident in the following SIR-C/X SAR example:

Example - NASA's Shuttle Imaging Radar-C and X-Band Synthetic Aperture Radar (SIR-C/X-SAR) mission was flown in April 1994 at an altitude of 225 km. Note, this is a very low LEO altitude. The C-band imaging radar operated at a frequency of 5.3 GHz, or a wavelength of 5.66 cm. Below is a notional SAR spot mode computation of the image time, given a resolution requirement of 1 m.

Given: $\varepsilon = 20°$
$h = 225$ km
$\lambda = .0566$ m
$v = 7.5$ km/s
$d_a = 1$ m

The given look elevation angle and spacecraft altitude results in a R_{max} of approximately 590 km. Therefore,

$$\mathrm{d_a} = \frac{\lambda \mathrm{R}}{2vt} \quad \text{or} \quad t = \frac{\lambda \mathrm{R}}{2v\mathrm{d_a}}$$

$$t = \frac{0.0566 \cdot 590{,}000}{2 \cdot 7500 \cdot 1} = 2.23 \text{ sec}$$

Airborne SAR systems fly at much lower altitudes than LEO satellite, but at much slower velocities. Thus, exposure time is roughly the same and problems associated with long exposure times persist. The U-2 and E-8 Joint Surveillance Target Attack Radar System (JSTARS) are two examples of current military SAR imaging aircraft. The U-2 is a stratospheric platform and thus has better access as its chief advantage. The E-8 is a much larger airframe, capable of a larger, more powerful SAR radar and antenna system. Another potential HALE advantage comes from its ability to provide greater link margin. With larger margins over satellites, a HALE platform might be better suited to support a higher frequency antenna. Thus, similar resolution could be achieved even at lower ground speeds.

HALE Example: A Global Hawk flying at 65,000 ft and 310 kts takes a 1 m resolution SAR image using an X-band (3 cm) radar. Find the image length in time.

Given: $\varepsilon = 20°$
$h = 65{,}000$ ft
$\lambda = .03$ m
$v = 310$ kts $= 160$ m/s
$d_a = 1$ m

The given look elevation angle and HALE altitude results in a R_{max} of approximately 57 km, and exposure time equals…

$$t = \frac{0.03 \cdot 57{,}300}{2 \cdot 160 \cdot 1} = 5.4 \text{ sec}$$

2. Near Real Time (NRT) Support

Fused battlefield and battlespace visualization and sensor-to-shooter capabilities require significant improvements over current systems. NTR requirements signify continuous coverage to support imagery and video. HALE platforms enjoy significant advantages over space-based systems in this arena. Extended dwell time is not possible from a single LEO satellite traveling at 17,000 MPH. Large LEO constellations be required to fulfill this need. GEO based platforms provide NRT capabilities, however, the high-resolution imagery needed would require technological breakthroughs from these distances. Although HALE platforms can't provide worldwide or global coverage, they do offer a means of NRT support in a specific theatre of operations.

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V. HALE PLATFORMS OVERVIEW

A. INTRODUCTION

This chapter is a descriptive chapter of the various HALE systems reviewed for this thesis. The following HALE platforms were researched to determine their potential in providing the communications “plumbing” and near real time ISR capabilities to meet emerging needs to become a network centric force.

A number of technological advances have occurred over the past ten years that have made HALE aircraft a viable option for fulfilling a unique niche in the national communications and ISR architecture. The first advance has been the widespread application of the Global Positioning System (GPS). This has allowed for the development of navigation systems using GPS satellites that permit continuous station keeping and autonomous flight routes. The next advance has been in the development of lightweight efficient solar cells to provide propulsion and payload power. A third advance has been in the miniaturization of electronics, which has enabled the lightweight construction of aircraft to reach and stay in the stratosphere. Finally, advances in avionics and communications have enabled an entire suite of autonomous unmanned craft.

The HALE systems research was conducted via site visits and contacts with the developers. For each system the authors give a brief background description, then provide information on specifications, advantages, disadvantages, mission capabilities, and remaining challenges. The HALE platforms fall into four general categories (see Table 8).

Hale System	Category	Power Source
Global Hawk	Unmanned aerial vehicle	Single jet engine
Proteus	Manned aircraft	Twin turbofan engines
Helios	Unmanned solar aircraft	Solar
Sounder	Unmanned airship	Solar
Sky Station	Unmanned airship	Solar

Table 8. HALE Categories

B. GLOBAL HAWK

1. Background:

The RQ-4A Global Hawk is a high altitude endurance unmanned aerial vehicle (HAE UAV) reconnaissance system designed primarily as an ISR platform, but studies are being conducted to determine the feasibility of using it as a wireless communications node. A recent Milestone II decision has transitioned Global Hawk from a DARPA Advanced Concept Technology Development (ACTD) project to an Engineering and Manufacturing Development (EMD) effort and low rate initial production (LRIP) has begun. The Air Force is the executive management agent for the program and Northrop Grumman is the primary contractor. Of the current UAV development programs, Global Hawk is the only one that can reach the stratosphere, provide a significant endurance capability, and have global access.

This HALE platform is the farthest along in its development with the most promise in becoming operational in the near future. Its primary purpose is to replace the role of the aging U-2 fleet of manned aircraft, but plans are ongoing to add to its mission capabilities. Global Hawk is suited to host a wide range of sensors and communications packages. The versatility of such a platform in future conflicts could aid military leaders in achieving a highly sought after network centric environment.

In terms on Navy involvement in the Global Hawk program, the deputy director is a naval officer who represents Navy interests; however, there is little evidence of significant involvement from the Navy in the program development. The Navy is still working on a mission statement that provides a vision for the development and operational employment of Global Hawk to support Naval requirements.

Figure 6. Global Hawk (From: USAF Global Hawk Program Overview Briefing)

2. Specifications

a) Overview

The global Hawk is a conventionally jet powered, single engine aircraft with an extensive on-board processing capability and communications suite. It requires a mobile Mission Control Element to control its flights but the aircraft itself it self-deployable. It recently validated it self-deployment capability by flying a preprogrammed route from Edwards AFB, CA to Adelaide, Australia. It has a fairly small logistical tail; the mobile support gear can be deployed worldwide using as few as two C-17 or three C-141 transports. [Nor01]

b) Cost

The Global Hawk is experiencing cost overruns, and has come under scrutiny by the Government Accounting Office (GAO). The GAO report indicates that additional cost overruns could push RQ-4A costs up to $15.3 million per vehicle. [USA01]

c) Size

Global Hawk has a length of 44.4 ft and a wingspan of 116 ft, which is roughly the same as a U-2. It is 15.2 ft tall and has a maximum takeoff weight of 25,600 lbs.

d) Performance Capabilities

The aircraft generator creates an additional 9.2 kwatts of electrical power to supply its payload. It has the capacity to carry 100 ft^3 payloads up to a weight of 1,500 lbs. The RQ-4A is capable of conducting missions up to 65,000 ft; however, the aircraft is not capable of performing a direct ascent to that altitude. After reaching approximately 55,000 ft it must trade fuel (i.e. weight) for altitude. During test and demonstration flights it has flown to an altitude of 66,400 ft. A standard mission profile would allow it to takeoff from an 8,000 ft runway, fly 1,400 miles to conduct its mission at altitudes up to 65,000 ft for a 24 hour period, then return to home base. It has already validated a mission endurance flight of 31.5 hours. Its max range is 12,000 miles and its loiter speed is 343 kts. [USA02]

e) Sensor Capabilities

Global Hawk is suited to carry a variety of sensors. It has an X-band Synthetic Aperture Radar that can obtain 0.3 meter imagery in the spot mode and 1.0 meter in the wide area search mode of operation. Operating in the Moving Target Indicator (MTI) mode, the radar has the capability of detecting either opening or closing targets at velocities as slow as 2.1 m/sec. from a distance of 20-200 km. Global Hawk is equipped to carry a 220 lbs Electro–Optic sensor that is based on COTS technology and can image in the visual and IR spectrums. It's designed to be able to image up to 1900 targets per day.

f) Communications Suite

The Global Hawk is equipped to operate in a wide spectrum of communications bands for both line of sight command and control and beyond line of sight data exchange. It is provided with UHF, X-band, Ku Band, and IMARSAT capabilities to pass intelligence data and receive command inputs from the Mobile Control Element.

g) Survivability

The aircraft has been provided with a wide variety of threat detection and self-protection capabilities for the combat environment. Overall, the projections are for one mission loss in 605 flights, according to the design team. For self-protection from enemy detection and attack it is equipped with the following systems:

- AN/ALR 89 Radar Warning Receiver to detect search and target radars
- ALE 50 Towed decoy designed to defeat surface-to-air and air-to-air missiles
- Onboard electronic jammers to counter search and track radars. [Nor01]

3. Advantages

Global Hawk offers a significant endurance advantage over today's manned aircraft. The UAV has a published endurance of up to 36 hours, which could increase by adding an in-flight refueling capability. By contrast, manned aircraft are and will continue to be limited by human endurance factors, regardless of any in-flight refueling capability. The Global Hawk has the flexibility to perform all communication and ISR missions to some extent. It is also the only validated system currently in a production phase.

4. Disadvantages

Global Hawk has a slight disadvantage in instantaneous area of coverage due to its altitude limitation of 65,000 ft, especially in the wireless communications role. Another disadvantage of Global Hawk is its complexity and subsequent logistical support requirements. In terms of maintainability, Global Hawk will require about the same amount of maintenance support as that of a typical jet squadron.

5. Mission Suitability

Global Hawk is the most versatile of the HALE systems, capable of performing every mission required in this area of research. The following are the missions it will be well suited to fulfill:

- Airborne communications node
- EO imaging
- IR imagining
- SAR imaging
- SIGINT
- COMMINT
- FISINT

6. Challenges

The challenges that Global Hawk faces include:

- Validating to the Federal Aviation Administration its capability to effectively and safely fly in controlled airspace with manned aircraft and land at civilian or military airfields.
- Developing communications payloads that with fit in the payload compartment and provide the widespread wireless connectivity envisioned in Network Centric Operations.

C. PROTEUS

1. Background

While conducting a document search on HALE platforms a high altitude manned aircraft was discovered that was being planned to provide commercial high volume wireless connectivity to metropolitan areas. The aircraft, called Proteus, was designed and built by Scaled Composites as a concept demonstrator and is currently a one-of-a-kind aircraft, not yet certified by the FAA. The original High Altitude Long Endurance Operation (HALO) concept was to have at least three aircraft flying eight-hour shifts over a metropolitan area to provide 24-hour communications coverage. Angel Technologies was the original partner for developing the telecommunications suite, which theoretically was to support up to 100,000 subscribers. The HALO concept has failed to materialize,

probably due to the changing economic condition in the telecommunications industry and the proliferation of cellular phone services. The aircraft has since been acquired by Northrop Grumman and is a current participant in NASA's Environmental Research Aircraft and Sensor Technology (ERAST) program. Northrop Grumman is currently using the aircraft as an avionics test bed for the airborne sensors it is developing for Global Hawk and other UAV's.

Figure 7. Proteus (From: NASA Dryden Flight Research Center)

2. Specifications

a) Size

The airplane can carry a crew of two and has a max gross weight of 15,000 lbs. It was designed with the landing gear spread wide to accommodate an antenna dish underneath up to 18 feet in diameter.

b) Performance Capabilities

Proteus has an endurance of over 10 hours and a range of over 2300 miles. Its maximum airspeed is 160 KIAS and it has a service ceiling of 61,919 ft with no payload and 55,878 ft with a 2200 lb payload. The runway length requirements are 7,500 ft. [Sta01]

c) Payload Capabilities

Its maximum payload capacity is 5,800 lbs, but higher weights reduce its loiter time and maximum altitude. It is designed to supply 19 kwatts of power, and can be expanded to 30 kwatts, if required.

d) Costs

A representative at Northrop Grumman provided the aircraft costs, which was about $8 million for small-scale production, or it could be leased at about $3,000 per hour. [Sta02]

3. Advantages

Proteus enjoys the most voluminous internal stores capacity of any HALE platform. It is capable of housing a large antenna and has the ability to generate ample power for communications related applications. This is beneficial in achieving link margins sufficient to allow for low powered, lightweight handheld and man-pack terminals for communications on the move connectivity.

Another advantage is that Proteus is a manned aircraft, which allows for flexibility in deploying the system. It does not require a ground based control system like UAV's. This craft could be rapidly self-deployable to its theater of operation.

4. Disadvantages

This craft has a number of disadvantages over the other classes of HALE craft: 1) it has the shortest endurance and range, 2) it has the lowest service ceiling and therefore the smallest area of coverage, and 3) it is a riskier asset to employ in a high threat environment due to possibility of losing aircrew to hostile fire. Proteus could acquire an in-flight refueling capability that would mitigate to an extent the range and endurance problem; however, the aircraft would continue to be limited by the aircrew rest needs. Finally, the aircraft is not yet FAA certified and the engines are still experimental with a number of concerns.

5. Mission Suitability

Proteus would be best utilized as a standoff platform. It would remain on the periphery until the anti-air threat was diminished significantly or eliminated. In the various communications and sensor hosting roles, it can function in every aspect.

6. Challenges

A Proteus type aircraft faces the following challenges:

- Getting a sponsor to promote it's potential for operational use. Although this is a proven aircraft platform it has lost advocates for wireless communications applications.
- Getting FAA certification
- Developing applicable payloads to support communications and ISR missions

D. HELIOS

1. Background

The Helios is a solar powered flying wing in development by AeroVironment Incorporated in Southern California. Like Proteus it is part of NASA's ERAST program. The company's future vision for Helios is as "a 'Near Earth Orbit' (NEO) satellite complement or substitute, with many potential uses including communications, imaging, and reconnaissance" [Hel01]. NASA plans to use the flight data as a baseline for possible future expeditions on Mars, since the atmosphere there will be similar to that at 100,000 ft above the Earth.

Helios is the latest and largest version of the Pathfinder series of solar powered wing vehicles. NASA has two current goals for the Helios. First it wants to validate a self-propelled flight to 100,000 ft. This was nearly accomplished on 14 August over Kauai, Hawaii when the aircraft made it under its own power to a height of 96,500 ft. This broke the previous propeller driven craft record of 80,200 ft set by the Pathfinder-Plus in 1998, and the horizontal flight record of 86,068 ft set by an SR-71 in 1966. NASA's second goal is to conduct a four-day endurance flight above 50,000 ft. This will be a milestone in the development of HALE systems. [Ste01]

2. Specifications

a) Size

The test aircraft weighs 1,557 pounds and has a wingspan of 247 feet, which is wider than a Boeing 747. Its length is 12 feet from front to rear and it is powered by 14 electric motors with fixed pitched propellers. The propellers are nearly 6 feet tall.

NASA Dryden Flight Research Center Photo Collection
http://www.dfrc.nasa.gov/gallery/photo/index.html
NASA Photo: ED01-0209-3 Date: July 14, 2001 Photo by: Nick Galante/PMRF
The Helios Prototype flying wing is shown over the Pacific Ocean during its first test flight on solar power from the U.S. Navy's Pacific Missile Range Facility in Hawaii.

Figure 8. Helios (From: NASA Dryden Flight Research Center)

b) Construction

The Helios is a very unique craft in that it is a modular design. It is a series of solar covered panels that connect to each other and are supported by a long carbon fiber cylindrical "spar tube" that runs the length of the craft. The spar sits inside the leading edge of the wing. The disassembled craft was viewed as it was preparing to be shipped to Hawaii for recent flight tests. The entire wing structure fit inside a single container that could be shipped on a truck.

The power for the Helios is supplied by 62,000 silicon crystal solar cells that can provide 35 kwatts of power. They are rated at about 18.4% efficient and are "bi-facial" meaning they can get solar energy from the top or bottom. Although these are not the most efficient cells available, they were selected because of their relative low cost and low weight.

The wings are constructed with 162 lightweight carbon fiber ribs wrapped in a clear plastic sheet to allow maximum penetration of light to the solar cells. The landing gear is constructed of simple bicycle wheels. [Hel01]

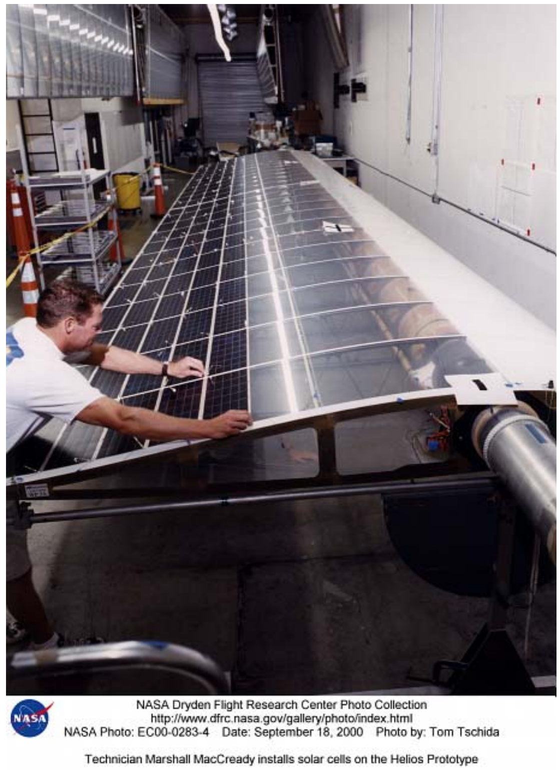

Figure 9. Helios Solar Wing (from NASA Dryden Flight Research Center)

c) *Performance Capabilities*

Helios does not have a very complex flight control system in terms of moving components. Small ailerons on the trailing edge of the wings control the pitch and roll while differential power setting of the 14 propellers controls the yaw. Each propeller is driven by brushless DC electric motors producing nearly two horsepower. It can operate at 15-18 KIAS, sufficient to overcome average winds at most altitudes depending on the time of year.

From an operational standpoint, the initial design is limited to the equatorial region (25° North latitude to 25° South latitude). These restrictions are due to

reduced sunlight and higher wind speeds during the winter months. This will not apply during summer months where it should be able to range up to the poles. AeroVironment claims to have a follow-on aircraft design that will be capable of year round operations in the range of 40° North to 40° South. [Tie01]

d) Payload Capabilities

Helios is designed to carry a 220 lb payload and supply it with 1000 watts of power. The wing "spar tube" has pod attachments on each main panel. The tube provides enough strength to carry the full payload at one point, or it can be spread along the full length of the wing. The follow-on design is capable of roughly twice the payload and significantly more power. [Hel01]

e) Costs

The cost of constructing the Helios prototype was approximately 15 million dollars. Large-scale production has the potential to significantly reduce per unit costs. The telecommunications vision would require at least two assets per region to ensure availability. [Hel01]

3. Advantages

The biggest advantage with the Helios is that it has now proven it is capable of reaching nearly 100,000 ft and the area of coverage at those altitudes for ISR and wireless communications is significantly greater than other HALE craft. Chapter IV analyzed coverage capabilities. Another advantage is that if it can overcome the nighttime power problem, it will have an endurance capability unmatched by conventionally powered craft. A third advantage is in its growth potential. Solar cell efficiency is continually improving. With the silicon cells at only 18.4% efficiency, there is potential for

significant power increases with only small increases in solar cell efficiency. There are also potential efficiencies to be gained through enhancements in the prop design.

4. Disadvantages

The first disadvantage is its unproven technology as compared to the Global Hawk. The next disadvantage is in its operational access. It will not be able to fulfill operational needs at the higher latitudes in winter conditions. The final disadvantage is its lower payload and power capability compared with the Proteus and Global Hawk.

5. Mission Suitability

The Helios should be able to perform most ISR and wireless communication missions. The ones it will have difficulty with are the SAR imaging and SIGINT geolocation capabilities because of its slow speed.

6. Challenges

The biggest challenge that Helios must overcome before being considered operationally viable for commercial and/or military applications is a nighttime power system. AeroVironment's current goal is to develop a regenerative power system based on fuel cell technology. A prototype device could be ready for flight-testing by 2004. The tests would be conducted near the equator to take advantage of daylight solar energy. Battery packs have proved to be too heavy for the craft so it has contracted with two major corporations to develop an electrolyzer. This is a self-contained system that separates water into hydrogen and oxygen for fuel then recombines them for reuse. Other options are to carry water that it expendable once separated so that it can increase its endurance. This would be their interim solution to get the Helios operational. [Tie01]

E. SOUNDER

1. Background

A HALE document search led to numerous solar powered airship companies with concepts and initial funding for large geostationary stratospheric craft. After further review only one was found that had actually flown an airship to stratospheric heights. The airship, Sounder, was designed and built at the Southwest Research Institute (SwRI) in San Antonio, Texas. Sounder is a concept demonstrator smaller than most stratospheric platform designs with a light payload and low power capability. A site visit of the program revealed that the airship conducted a successful launch on 27 Apr 1999. During that demonstration test, Sounder reached an altitude of 72,000 ft and stayed airborne for six hours. This was first the flight-testing of a solar powered, high altitude airship since the 1970's. The test partially verified the super-pressure design; however, a failure in the solar power propulsion system brought early termination to the flight. [Int01]

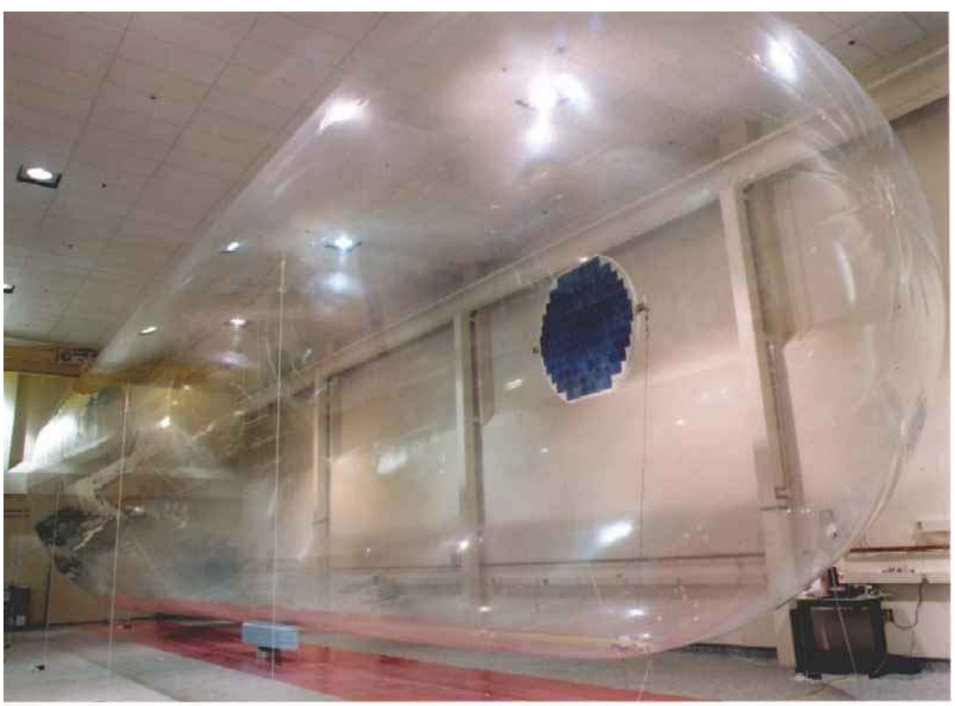

Figure 10. Sounder (From: Autonomous High Altitude Airships Brief)

2. Specifications

a) Size

The airship is 124 feet long with a diameter of 24 ft. Its operating weight is 219 pounds, including about 14 pounds for ballast.

b) Structure

Sounder is constructed of a thin clear 1 mm thick hull of nylon 6 material, which is a commercial off the shelf (COTS) item. An Intel 386 class computer that utilizes GPS for position keeping controls its guidance system and controls the gimbal mounted electric prop for station keeping. A small solar powered two-blade propeller weighing a mere two pounds drives the airship propulsion system. Its single solar array is unique in that it suspends internally from a set of lines that can turn it to maintain an optimum beta angle with the sun. The solar cells are only rated at around 10% efficiency. [Int01]

c) Performance Capabilities

The Sounder has a very low maintenance and logistical requirement. It can be carried in a single truck with all of its support gear and launched from a small clearing. This makes it particularly useful to tactical users because it is designed as a launch and leave item. It is injected with a predetermined amount of helium that will fully inflate the airship upon reaching a particular pressure altitude. Once on station it is restricted to that altitude. According to the design team at SwRI, the airship does not require lengthy FAA approval to fly through controlled airspace. Recall that Global Hawk requires certificates of approval (COA's) before every flight. Because Sounder transverses the controlled airspace nearly vertically, and rapidly, the only requirement is a Notice to Airmen (NOTAM). [Int01]

Sounder has limited maneuverability. It is designed to be able to station-keep in winds averaging less than 20 kts. This equates to about 4 KIAS. Its current propulsion system is capable of 29.5 kts in daylight and 8.5 kts at night while on battery power. The airship will be both altitude and latitude restricted; otherwise, users risk losing the airship to the winds, an important operational consideration. The only method of retrieval is via rupturing the cell using a small explosive device. Sounder recovers by parachuting to the earth. It carries two parachutes; one recovers the payload and one recovers the solar array, hull, and motor. [Int01]

d) Payload Capabilities

The Sounder is only capable of supporting a small payload with low power needs. It can support a 10 lbs payload and supply it with 100 watts of power. These numbers are extremely small by conventional aviation and satellite standards; however, Sounder's payloads do not require the same degree of protection from shock and vibration hazards. It is essentially a free-floater, immune to rapid accelerations, rough landings, violent launch environment, etc. Consequently, the payloads can be made very lightweight, with just the essential electronics. The SwRI designers believe communications up to about 2.5 GHz can be achieved by using lightweight linear array antennas. [Int01]

e) Cost

Only "rough" cost estimates for the Sounder airship were obtained. To date, developmental costs for the current vehicle are about $300,000. The system is being promoted as an affordable expendable. Large production numbers could drive per unit costs well under $100,000. [Int01]

3. Advantages

Sounder's simplicity, affordability, expendability and rapid deploy ability will be an asset in a high threat combat environment. As an expendable device, it can become an allocated asset to the tactical commander level. The commander would have the autonomy and flexibility to expand both communication and sensor ranges rapidly to meet the threat.

4. Disadvantages

Sounder is very inflexible in terms of mission profile. Its altitude must be predetermined and cannot be changed once airborne. Its slow speed significantly reduces its operational employability, and could force early mission termination in situations where station keeping could not be maintained. Small payload capability and low available power is an additional problem area for Sounder. Because of its requirement for light payloads, it might not be possible to find COTS technology that can provide significant military applications. Payload developmental costs would increase the bottom line.

5. Mission Suitability

Sounder will be restricted in the number of missions it can perform simply because of its slow speed and low payload capacity. In the wireless comms role, it will be restricted to the UHF spectrum because it will technologically difficult to carry a high gain antenna. For ISR, it will not be appropriate for the SAR or any role requiring heavy payload mass.

6. Challenges

There are a number of challenges with this craft. The first is with the propulsion system. On its maiden test flight, as the airship became fully inflated, it began a series of rapid pitching moments before reaching horizontal flight attitude. The force of these gyrations snapped the small propeller, thus ending the station-keeping portion of the test. Additional tests are planned in 2001.

Another unknown is the affect of thermal cycling. The airship has not flown at night and the engineers are not sure how the super-pressurized bladder will handle the temperature changes. There is simply no baseline of data to pull from, according to the engineers. The potential change in volume might bring the craft down. More data points are also needed on the heat dissipation from the solar cells. Since the cells are internal, the engineers expressed concern over the heating and subsequent pressure increase. Too much pressure on the hull could rupture the craft. [Int01]

F. SKY STATION

1. Background

Of all of the systems researched, the least developed is in the area of large solar powered airships. Designs promised large superstructures, capable of accommodating heavy payloads and large power generation systems. A number of companies have formed promoting these ideas and searching for funding, however, to date, none of these systems has reached the prototype stage.

One such system is Sky Station. Numerous publications and a professional website are devoted to this Washington DC Company. They following data were obtained:

- The timeline for fielding the system was on-schedule for delivery in 2002.
- The airship would be able to remain on station for a five year period in stratospheric winds of up to 35 m/sec (68 kts)
- Payload capacity of up to 1800 kg
- Capable of supplying 15 Kwatts of continuous power
- Support to one million communications customers using the 47-48 GHz frequency band or three million customers using 3 GHz
- User terminals would be similar to current cellular phone size and power
- A 5-inch directional flat antenna would be required for the higher frequency bands. [Phi01]

The Federal Communications Commission approved the use of the 47-48 GHz range for use by HALE platforms, but that has proven to be the only real success thus far. Sky Station had entered into initial talks with Lockheed Martin Global Telecommunications to build the airship, however, the authors discovered that the partnership has dissolved due to lack of funding.

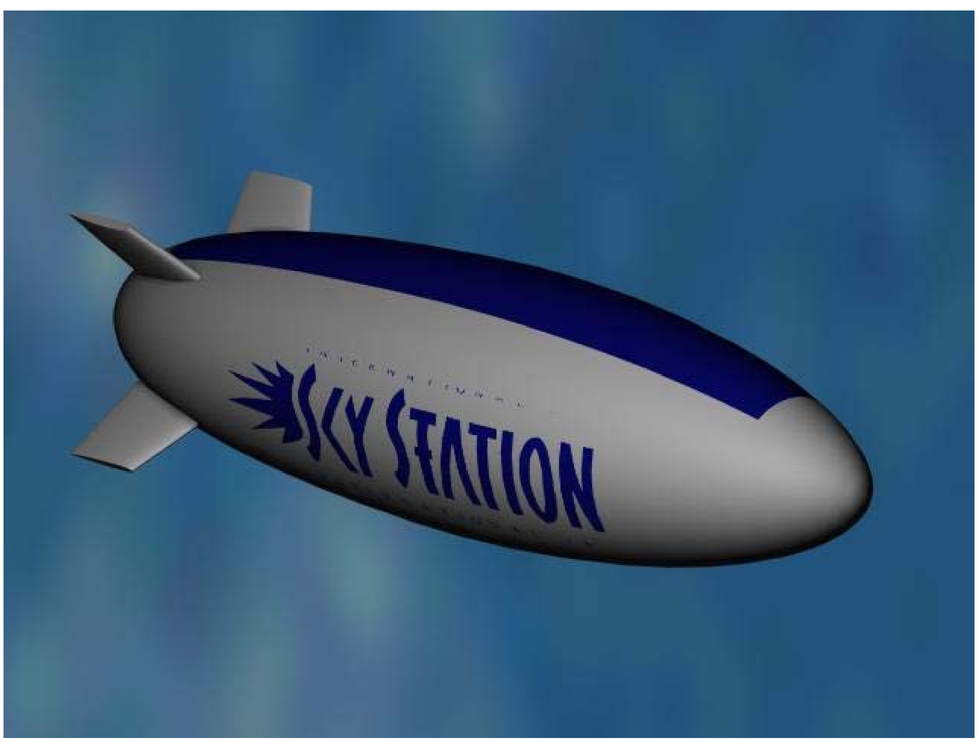

Figure 11. Sky Station (From: Sky Station web site)

2. Specifications

There are only artist's depictions of what the Sky Station airship would look like. Vehicle size is variable, custom configured but expected to the average approximately 515 ft long and 203 ft in diameter at the widest point. A large array of solar cells will cover the top of the ship. It is constructed of a lightweight material but the type is not identified. [Air01]

3. Advantages

The advantage that this system if ever fielded is its tremendous endurance and large payload and power capacity.

4. Disadvantages

There are numerous disadvantages that this system faces. The first is its deployability. Because of its size, there will be difficulties in developing a reliable method to transport it worldwide and deploy it for tactical uses. Its slow speed makes it less responsive to self-deployment. Its operational range will be restricted in latitude, like Helios, due to lack of sufficient solar energy. Its large size will increase its detection potential. Finally, its restriction to a specific pressure altitude gives it less flexibility.

5. Mission Suitability

The sky station would be best suited in the communications role but can perform some SIGINT and IMINT roles. It would not be well suited for the SAR role.

6. Challenges

The first challenge is simply a lack of a prototype from which to build a baseline. Deployment by 2002 is impossible. Additional issues all relate to hull strength. In particular:

- Power – The artist depictions of solar cells on the hull cause a number of difficulties. First they will build heat that will potentially transfer to the hull and rupture it. The cells will be heavy, further increasing the stress.
- Thermal – Besides the solar cells, normal day/night thermal cycling will provide significant stress.
- Propulsion – The propulsion system will be a major hurdle. This is a large airship designed for speeds of up to 68 kts IAS. It will not only require large propeller blades, but additional structural strength for mounting the motors in the rear of the craft.
- Deployment – A craft this large will require a significant amount of ground support hardware that increases the risk of accidental rupture. Launch and recovery operations will be demanding events.

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VI. SURVIVABILITY

A. INTRODUCTION

Concerning the issue of HALE platform operations in a combat scenario, there are agencies such as the Naval Space Command and Marine Corps Warfighting Laboratory who have expressed doubt over their survivability against hostile actions. It is believed that this lack of survivability hinders HALE effective application for widespread military needs. In this chapter two major areas on survivability are examined. First the authors will analyze space vulnerabilities as they relate to natural causes, launch risks, and hostile actions. Secondly, HALE platform capabilities are analyzed in the same general categories.

B. SPACE VULNERABILITIES

Space can offer a safe haven from many hazards but it is not a benign regime and there are many risks associated with space applications. Before looking at the survivability issues with stratospheric platforms, a review is done on some of the vulnerabilities involved with space in general. They come under three main categories; natural causes, launch risks, and hostile actions.

1. Natural Causes

a) Orbital Decay

LEO satellites below 600 km experience significant orbit decay due to Earth's atmospheric drag. For an example, a 50 kg/m2 satellite at an altitude of 600 km can be expected to remain in orbit for 3430 days* (9.4 years), whereas the same satellite

* Based on worst-case scenario, operating at solar maximum in the 11 years sunspot cycle.

at 550 km would decay in 801 days [Wer99, back tables]. Satellites designed to operate in Earth's drag require onboard propulsion systems, which add complexity, mass, and cost. In cases where propellant is depleted or the satellite propulsion system malfunctions; a manned support mission could attempt a recovery operation. However, this is a costly solution with much risk and significant scheduling difficulties.

b) Scintillation

This phenomenon affects SATCOM in the UHF bands and is caused by ionosphere disturbances occurring in the 40-600 km altitude range. The disturbances cause rapid phase and amplitude fluctuations of satellite signals observed at or near the earth. The most intense scintillation events cause rapid degradation of radio signals between the hours of 2000 to 0300 and occur within 20 degrees of the Earth's magnetic equator. This encompasses over one third of the globe and is where most of the recent US military operations have occurred. [Bal01]

Scintillation can adversely affect frequencies up through L-Band (2 GHz). The military UHF band, specifically 200-275 MHz, is particularly susceptible and is where the UHF Follow-on (UHF/FO) and Fleet Satellite Communications (FLTSAT) satellites currently operate. Though significant scintillation events can be predicted, there exists the potential for communications degradation during these periods. Decreased operational effectiveness is the ultimate penalty. Combat operations occur around the clock and the United States relies on its capabilities to "own the night". Assured access to wireless communications is required in order to support dispersed units and provide reachback capabilities to achieve mission success. [Bal01]

c) Charged Particles

Space is a harsh environment filled with high-energy charged particles produced directly from the solar wind and indirectly from the Van Allen belts. They can and have harmed spacecraft in three ways:

- Charging – the particles can build up on parts of the spacecraft and destroy electronic circuits.
- Sputtering – sand-blasting effect that can destroy thermal coating and sensors over time
- Single Event Upsets – a high energy particle can penetrate the spacecraft and cause a "bitflip" in electronic circuitry. [Sel94 p.74]

Much time, effort, and money has been allocated to shielding spacecraft from these damaging affects.

d) Space Debris

The number of objects in space continues to grow as an ever-increasing number of nations become "space ferrying." Currently, the US tracks nearly 10,000 objects in space larger than softball in size. Collisions with smaller particles, not tracked, traveling at velocities on the order of 17,000 MPH can cause significant damage. In 1994, the odds of a LEO satellite striking a 1 mm size object on orbit were 1/1000 over a one year period. Those odds are increasing. [Sel94, p. 71]

2. Launch Risks

As with any system there are associated risks with their operational employment. Many consider satellites to be relatively secure once established on orbit. However, getting there is still not a "sure thing" and a look at some recent launch mishaps show that it is not only costly in terms of dollars, but also in supporting national security objectives.

Space launch is "rocket science," and a look at the track record shows it can be a problem. Over little more than a one-year period from 1998 through 1999, the US Air

Force had six launch failures, which either ended in destruction or with satellites stranded in useless orbits. The total cost of these failures was about 3.5 billion dollars.

Three of the six failed launches were attributed to the Titan IV rocket. The significance can be expressed simply in terms of the lost payloads: a National Reconnaissance Office satellite on 9 Apr 1998, a DSP satellite on 9 Apr 1999, and a MILSTAR communications satellite on 30 Apr 1999. [Hil99] These failures cause a chain reaction of difficulties; new replacement spacecraft must be produced, another launch vehicle contract must be let, and a new launch date scheduled. The US typically doesn't have many, if any, spare spacecraft sitting around for just such a situation. The high cost of spacecraft preclude spare procurement, for instance, MILSTAR is an $800 million satellite system. [MSC99] The end result could be a supportability gap - the inability to provide space assets for the warfigher's needs.

3. Hostile Actions

The final category researched concerns hostile action. Most of the major world powers have publicly denied they have active programs involving anti-satellite (ASAT) technologies. It might not be wise to trust that this will continue to be the case with potential adversaries. Many countries believe the United States' reliance on space support is its "Achilles heel," and it would be in their best interest to have the capability to deny that access. The Secretary of Defense and the incoming Joint Chiefs of Staff have both predicted that it is only a matter of time before space is militarized.

Few nations have the ability to reach geostationary orbit, so it is safe to assume that those platforms are the least vulnerable. LEO assets are another story though.

Current ASAT technology is available to a growing number of third world countries. These countries are acquiring the capability to place payloads into LEO, thus posing a threat to other LEO systems. Russia has developed numerous ASAT systems since the 1960's; co-orbital, low-level nuclear, laser systems, and aircraft launched missile systems. The most feasible of these is the co-orbital attack system. The system uses a radar tracking system for terminal guidance and boosters to correct for orbital

injection errors. From 1968-1971, five out of seven attempts were assessed as successful. This series of tests validated an operational envelope of 230 – 1000 km. [Joh94 p. 346-347]

Many spacecraft have no self-defense capacity, and are thus vulnerable to attack. A LEO spacecraft's orbit crosses most of the globe; therefore, there will be a number of difficulties in protecting them. Upgrading systems already in orbit with self protection devices would be fiscally and technically challenging. Determining the origin of an ASAT attack is another posing question.

C. HALE VULNERABILITIES

While it is not possible to compare HALE and satellite vulnerabilities in the same specific areas, it is possible to describe vulnerabilities in the same general categories; natural causes, terminal risks, and hostile actions.

1. Natural Causes

HALE systems are not vulnerable to the natural causes that affect space systems, but they are affected by weather phenomena. The most significant effect will be during accent to their stratospheric stations. Storms, icing, lightning, and turbulence will all potentially damage these craft if not avoided. Once on station, the only real concern will be winds, which can push them off course.

2. Terminal Risks

HALE terminal phase operations can be more likened to aircraft than spacecraft. Like spacecraft, the launch phase will provide risk to HALE employment; however, there exists an additional recovery risk that will affect the rapid re-employment of the asset.

3. Hostile Actions

Threats to HALE systems from enemy action come in two categories: surface–to-air missiles (SAM's) and airborne threats. A consideration of airborne threats would not be complete without at least mentioning the ability to negate that threat. The concept of aerospace control is a core competency of the USAF. Together with the air capabilities of naval forces, the US has successfully deterred enemy air actions dating back to the Korean War. Aerospace control assures the friendly use of the aerospace environment while denying its use to an enemy. [Sec97, p. 29]

In order to keep this chapter in the unclassified realm, an analysis is provided on generic survivability issues that affect HALE platforms.

Further research is required to determine specific SAM and airborne threat capabilities to HALE craft, which is beyond the scope of this thesis. In general though, a brief review of threat systems show that there are limited systems with the capability to effectively reach the stratosphere. For those systems that can reach stratospheric heights, HALE platforms can be deployed at standoff distances while still providing effective capabilities.

The following survivability characteristics show general threat issues where HALE platforms have or lack abilities to operate in a high threat environment.

a) Signatures

(1) Infrared (IR) - Many missile threats use infrared guidance systems for the tracking and terminal phases of guidance; therefore, conventionally powered HALE vehicles will be most susceptible to the IR threat. However, all of the solar powered craft will offer natural protection against these systems.

(2) Radar - Most of the platforms researched are large, and thus will exhibit large radar cross-sectional areas. What is unknown is the degree of stealth ness to be obtained by using composite materials vice metals.

(3) Visual - Large aircraft usually make for better, more pronounced visual signatures. Sounder, for instance, has an obvious visual signature due to the sunlight reflections. Even at stratospheric heights (70,000+ ft) the airship was visible to ground observer. Condensation trails (contrails) are another visual cue military aircraft strive to avoid. The stratospheric atmosphere is nearly deplete of water vapor, making this a non-issue while at station-keeping altitudes.

b) Electronic Protection

Currently, the Global Hawk is the only system designed with a suite of self-protection gear to counter threat missile systems. A Radar Warning Receiver (RWR), Decoys, and self-protect jammers could be installed on any HALE craft. However, additional protection features come at the expense of payload in terms of size, weight, and cost.

c) Maneuverability

Integrated RWR systems can initiate defensive maneuvers to aerodynamically defeat threat missiles. The slower HALE platforms, such as Helios, Sounder and Sky Station, will not be capable of effectively employing such a RWR system.

d) Altitude Safety

The stratospheric regime offers natural protection against systems with insufficient boost capacity to reach HALE stations. It is a relative issue within the HALE classes. The conventionally powered platforms are typically more altitude constrained. In particular, Proteus will be most vulnerable in terms of altitude protection.

Additionally, HALE craft will enjoy a long line of sight horizon at these altitudes. This will allow for increased standoff ranges, well beyond the FLOT, while still providing the requisite coverage for the mission at hand.

e) Doppler Protection

Slower HALE systems have an advantage over higher speed systems in avoiding detection from certain pulse Doppler radars.

These vulnerabilities were only those the authors felt were important in relation to HALE survivability. Overall, it shows that no C4ISR platform, from space or the stratosphere, will be impervious to attack or risks. Further analysis is required to determine which systems will fair better in an operational environment.

VII. CONCEPT OF OPERATIONS

A. INTRODUCTION

This chapter will provide analysis in a number of CONOPS areas. First, it will detail the range of military operations where HALE craft may operate. Secondly, it will detail issues involved with deploying HALE assets into a theatre of operations. Thirdly, it will describe the various mission support areas where HALE craft will be utilized. These specific mission areas include: communications connectivity, theatre ISR support, Blue Force Tracking, strategic deterrence, and GPS support. Finally, it will provide the reader notional coverage capabilities for real world scenarios.

B. RANGE OF MILITARY OPERATIONS

The range of military operations is defined in a number of different ways. For the purpose of this research, it is defined in terms of the *Joint Doctrine Encyclopedia*. Military operations are divided into two general categories: war and military operations other than war (MOOTW). War involves high-risk combat operations to forces while MOOTW operations can either include combatant or noncombatant operations. War examples include attack, defend, and blockade missions. MOOTW, however, is more expansive and can include peace enforcement, counter-terrorism, show of force, raid, strike, peacekeeping, Noncombatant Evacuation Operations (NEO), Nation assistance, counterinsurgency, freedom of navigation, counterdrug, protection of shipping, and US civil support. [JCS97 p. 609]

The authors, in determining CONOPS support, have concluded the HALE platforms can effectively support each of these missions in some capacity. HALE platforms can be more easily integrated into MOOTW operations and combat operations that do not present significant anti-air threats. However, there are still employment considerations that make them effective in all ranges of operations.

As HALE platforms become operational, they will need to be included in the Time-Phased Force and Deployment Data (TPFDD) system. This information is included in the Joint Operation Planning and Execution System (JOPES) data portion of the operations plan. For each HALE platform, detailed deployment data must be generated, to include, sequencing into the theatre, transportation requirements and logistical support. [JCS97 p. 703]

In general, for all missions where hostile actions do not present dangers to HALE craft, they would deploy with the initial forces and be situated directly over the area of interest for maximum coverage and support. In conflicts involving threats to HALE craft, they are envisioned to provide standoff support to the front lines and transition forward as the front lines advance or the SAM and anti-air threats subside.

C. EMPLOYMENT ISSUES

The following will detail general CONOPS issues for utilizing the various HALE platforms researched in this thesis. The authors envision a combination of HALE assets acquired because they each offer unique strengths, however, the specific type and number are beyond the scope of this research. The overall command and control structure is not specifically defined by the authors, but the general concept is to assign both the platform and payload to the JFC for coordination.

1. Global Hawk

The Global Hawk will be flown as a national and theater asset. Developers are working to obtain Federal Aviation Administration (FAA) approval for the Global Hawk to have widespread authorization to fly in controlled airspace. In the scope of this thesis, the focus is more on supporting tactical users.

When required, the Global Hawk will be assigned in support of the Joint Force Commander’s (JFC’s) requirements, with the Joint Force Air Component Commander

(JFACC) as the principal agent for integrating and synchronizing its use. The minimum support unit will include: at least two air vehicles, a launch and recovery element (LRE), and a mission control element (MCE). Actual numbers of system components will depend on the specific theater employment concept. [USA02]

Global Hawk will notionally deploy from a NATO standard, 8000 ft x 150 ft wide landing strip, which would be either a main operating base (MOB) or a forward operating location (FOL). Ideally, once deployed, it would recover at a FOL for maximum on-station capabilities. [USA02] In the ISR role, sensor information will be sent to the appropriate users for processing, exploitation, and dissemination. In the communications role, multiple units might be required for theatre wide support.

2. Proteus

The envisioned deployment CONOPS for a Proteus class craft would be similar to the Global Hawk. Once assigned to a JFC, Proteus would be self-deployed into theatre while is logistics support followed. There are two main differences between a Proteus and Global Hawk employment: 1) Proteus would need to operate from a FOL to be effective because it has a much shorter range than the Global Hawk, and 2) Because it is manned, Proteus is unlikely to operate close to the FLOT, especially in the presence of a credible anti-air threat.

As far as mission employment, Proteus is envisioned to be more applicable to the communications support roles rather than ISR. Its large antenna makes it more effective as a communications platform

3. Helios

Helios, like the Global Hawk, can provide both national and tactical support in both ISR and communications roles. As a communications platform, Helios can offer the higher look angles needed for urban environments. The authors envision the Helios being

employed in the lower latitudes whenever needed and at higher latitudes in the summer months because of its solar energy limitations. High stratospheric winds pose an additional problem for Helios operations.

Helios is uniquely suited to operate in a strategic deterrence role, due to its large coverage area and long dwell. The authors envision Helios in service, providing a semi permanent presence over key strategic areas of interest such as the Straits of Taiwan.

Helios is slow, but modular, and should therefore be transported into the theatre of operation then launched. A wide tarmac or runway is all that is required for launch.

4. Sounder

The authors envision the Sounder as a quick response, rapidly deployable, disposable asset. Sounder could be launched from an area near the FLOT or from the deck of a ship to support mobile communications expansion or ISR on a smaller scale because of the low payload capability. Several Sounders could be packaged and transported as part of the normal deployment pack-out. A shelf life would have to be identified and any special storage and handling considerations addressed. Payload integration and checkout would be accomplished prior to launch, probably in an enclosed, protected space. The actual launch would probably require fair weather to mitigate deployment and payload risks. Launch operations could be conducted with a crew of no more than five individuals. Current and forecast weather data, especially wind information, would be used to determine the best launch location for precise insertion.

Retrieval issues will need to be considered since it will possibly drift over hostile territory, or through international airspace in high winds. It's expendable status means it can be employed in any threat scenario. Preprogrammed waypoints inside a "track box" would be uploaded prior to launch. If Sounder fails to maintain the "track box" or drift out of LOS range, an automatic destruct mechanism will terminate the mission.

D. MISSION SUPPORT AREAS

In the mission support capabilities, there are five envisioned general support missions.

1. Communications Connectivity

As mentioned in previous chapters, it is clear that communications connectivity provided by HALE craft can be a significant force enabler in the Network Centric Environment. Effective employment will depend on the communications payload capability and HALE positioning to best support the JFC's operational goals. Backwards compatibility, interoperability and scalability should all be key design consideration for HALE systems development. Communications payloads should not only crosslink with other HALE systems, but with both commercial and military SATCOM systems.

The JFC commander will ultimately determine his connectivity needs. However, generally in low threat environments, HALE craft should be placed directly over the theatre of operations to provide maximum connectivity to all warfighters. Considerations should be made to move it as far forward to the FEBA as necessary to reach front line troops with the highest priority in communications support. In high threat scenarios, HALE will typically operate in a standoff mode and still provide reachback capabilities to front line units.

2. ISR Support

ISR support offers the JTF commander numerous options. First, commanders must prioritize needs in terms of intelligence requirements. Once these priorities are decided, the HALE platforms will again be configured with the appropriate sensors. The positioning of the ISR platforms will likely be as far forward as possible depending on the operational picture and threat situation. This will give the HALE system maximum capability to monitor the enemy order of battle. Unlike many of today's sensor assets,

HALE products will be sent to both the front line users and to supporting intelligence agencies for further analysis. This capability will enable the NRT support and sensor-to-shooter requirements of the future.

3. Strategic Deterrence

This is a mission that will use many of the same ISR assets but have a different focus in terms of its mission. Studies are currently being done to determine the feasibility of using HALE systems, particularly the solar powered craft, as part of the US's strategic defense architecture. Notionally, they will be able to perform functions such as detecting missile launches and providing tracking data to the missile defense systems that are in development.

Additionally, deterrence capabilities are provided in the strategic realm because HALE systems can provide continuous surveillance and warn of potential military actions. This long-term surveillance, particularly on Naval activities, provides deterrence against surprise attacks from potential adversaries.

4. Blue Force Tracking

Blue force tracking (BFT) involves communicating and disseminating a unit's Global Positioning System (GPS) position via a low power, low data rate beacon transmission. Although the function of blue force tracking is essentially provided via the connectivity capabilities of HALE systems, the authors felt this mission should be briefly covered because it is a mission area that has been an elusive goal and will only get more difficult in the Network Centric Age.

Why is it so difficult to track and identify friendly forces? The U.S. military's doctrine exploits the battlefield through fast tempo maneuver warfare. This means that the forward edge of the battle area (FEBA) and fire support coordination line (FSCL), which are the primary means of coordinating fires, can rapidly and unexpectedly change.

Knowing friendly positions is essential. The Persian Gulf conflict proved how modern maneuver warfare still requires a better system of tracking friendly forces in a combat environment. Had US Forces become more entangled with Iraqi forces, the friendly fire situations would have likely been higher. The following statistics relate fratricide incidents during the Persian Gulf conflict:

- Over 70% of US tanks and armored personnel carriers hit by fire were from friendly forces
- At Al Kafji, an errant A-10 Maverick missile hit a Marine unit
- At Al Kafji, an A-6 bombed a Saudi unit
- An A-10 attacked 2 British APC's
- An Apache helicopter attacked 2 Army APC's
- A Marine gunship attacked a Saudi National Guard unit
- 2 additional British APC's were hit. [Cla99, p 420-425]

Currently, there is a program for Space-Based Blue Force Tracking (SB-BFT) that provides support on a global scale by tracking friendly forces. These assets will, however, be insufficient to track the large numbers of troop needed in major conflicts. The authors feel that HALE platforms offer the best answer to BFT shortfalls because of their long dwell and good coverage capability.

5. GPS Support

This mission, like the BFT mission, essentially relies on connectivity capabilities. However, it should be briefly mentioned because it is a defined new mission in the UAV roadmap. The concept is to use HALE platforms as GPS pseudo-satellites to provide theatre and tactical users clearer reception and reduced vulnerability to GPS jamming through higher retransmission signals. The specific hardware and software requirements are not yet identified. [OSD01, p ii]

E. CONOPS SCENARIOS

1. Chinese-Taiwan Conflict

In the ongoing tension in the Taiwan Strait between China and Taiwan, there is a requirement to maintain situational awareness on Chinese military activities as they relate to Taiwan. The denial of a surprise attack and thus deterrence is the objective. Space assets alone will not provide for the continuous dwell time and high resolution required, however, a HALE platform could complement space platforms to attain NRT surveillance.

If the tensions in the region rise, the US would desire continual monitoring of the situation with ISR assets. Global Hawks could deploy from bases in Japan and provide 24/7 coverage.

Figure 12 depicts a Global Hawk class platform operating at 65,000 ft in international waters monitoring the Chinese order of battle. The figure shows that most of the littorals can be monitored by one craft. Scalability in terms of numbers of craft could cover the entire littoral region. The 0° look angle, which covers the entire map is not practical for imagery but still provides various SIGINT collection capabilities.

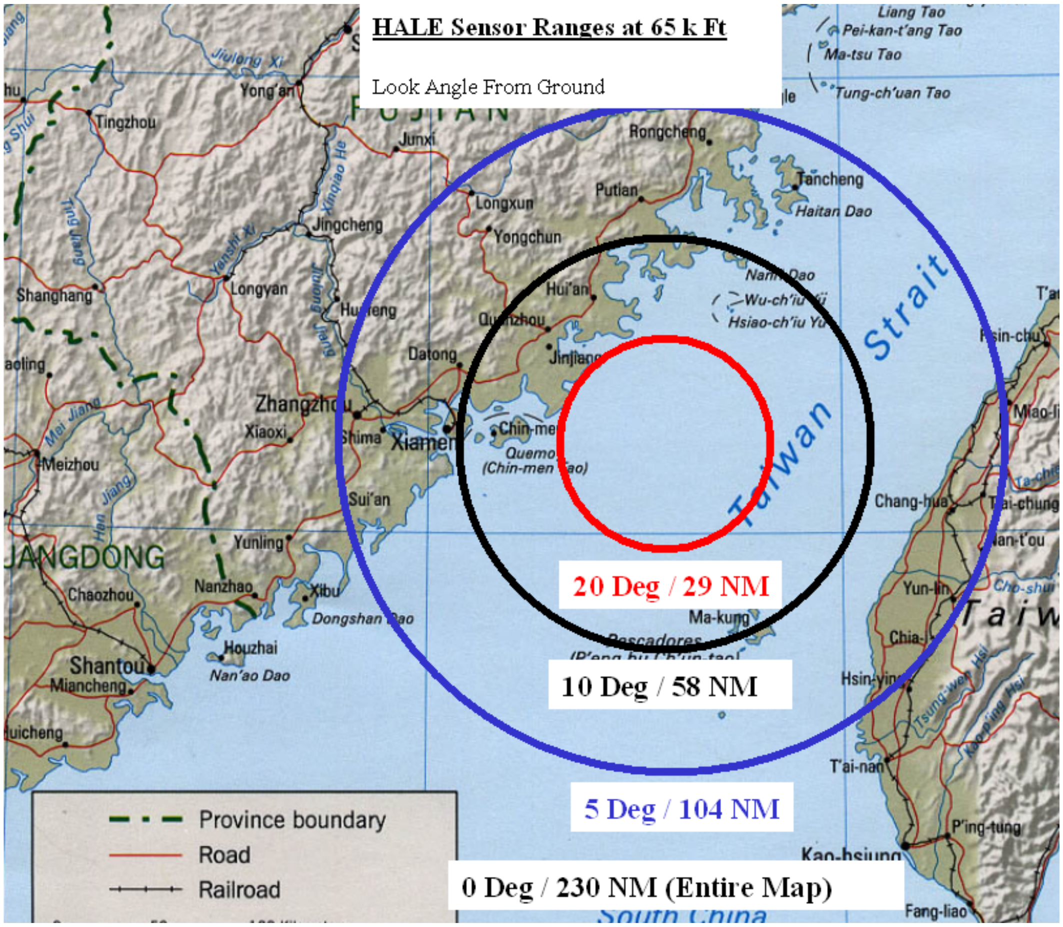

Figure 12. Taiwan Strait Scenario

2. Middle East Conflict Scenario

There is a continuing US presence in the Persian Gulf to ensure stability in the region. The main threat to Kuwait still comes from Iraq. If there is aggressive activity coming from Iraq, there will be a requirement for both communications connectivity and ISR support. Again, space assets will fall short.

HALE platforms can be deployed in theatre from local bases and provide immediate support in all ISR and communications roles. Figure 13 depicts a Helios class HALE platform supporting ISR and communications from a station in Kuwait at 95,000 ft. The imagery support from 10° and above covers the entire Kuwait border with Iraq

while SIGINT and communications capabilities can range the entire theatre. The 0° look angle, which provides SIGINT and connectivity support, encompasses the entire map.

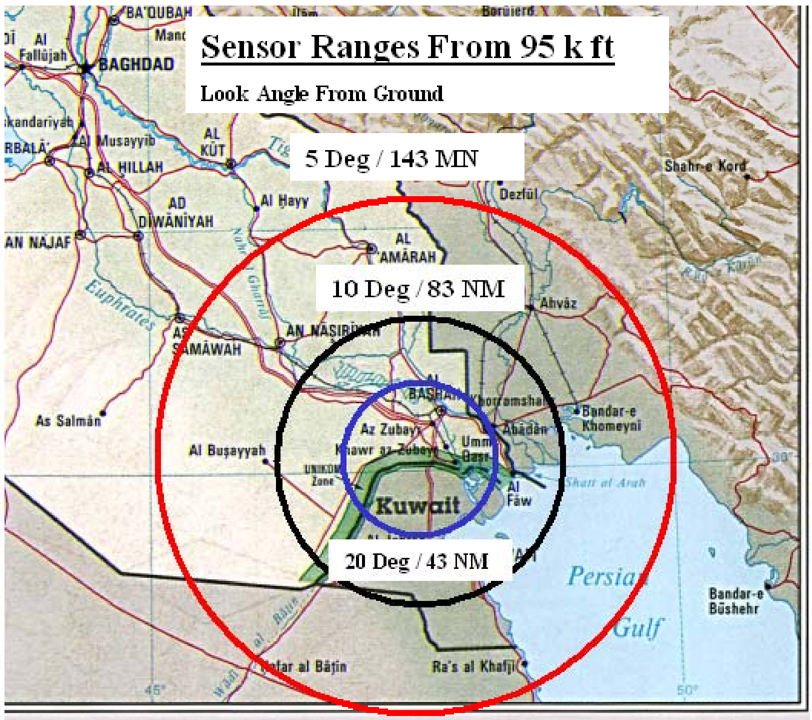

Figure 13. Middle East Scenario

VIII. HALE COMPARATIVE ANALYSIS

A. INTRODUCTION

In previous chapters, the authors laid the groundwork for arguing that HALE platforms are required for warfighter support. The various developmental HALE systems were described and their CONOPS envisioned. This chapter provides a comparative analysis between the various HALE systems in terms of; instantaneous area of access, costs, endurance, survivability, feasibility, flexibility, and responsiveness. Many of the HALE systems are still in their infancy, so a true trade-off studies is not possible. What is possible is a comparison and illustrative analysis between the HALE systems researched.

B. COMPARATIVE PROCESS

This process consists of defining the authors measures for each category, bounding the problem, providing weighted criteria where needed, and comparing the HALE platforms in each category.

C. METHODOLOGY

The alternatives considered are the same five platforms described in detail in Chapter V - Global Hawk, Helios, Proteus, Sounder, and Sky Station.

Key system design criteria were selected and weighted based the authors' judgment for a near term and long term HALE solution. Many of the measures are disaggregated into sub criteria. The sub criteria are also weighted in order to further hone the user's desires.

Criteria are scored using utility curves, and for the purpose of this study, have been normalized to fall between 0-10. The best alternative is chosen after aggregating the

criteria scores and identifying the highest total score for a short-term and long-term HALE solution.

D. ANALYSIS

Trade criteria were identified in areas that have the greatest potential for affecting the successful design and deployment of HALE platforms. The following categories were selected:

- Instantaneous Access Area
- Cost
- Endurance
- Survivability
- Feasibility
- Flexibility
- Responsiveness

1. Instantaneous Access Area

If HALE platforms are to provide satellite augmentation and supplementation, they will require large area coverage to support the maximum number of troops possible. A definition and calculation of IAA was provided in Chapter IV.

For this comparison, the authors used the lowest IAA measurements based on a typical ISR airborne altitude (RC-135) of 35,000 ft with a look elevation angle of 0° and a score of 0. The upper limit was set at 105,000 ft, which is near the current upper reaches of HALE craft with a score of 10. A linear utility curve was utilized to compute the score for each platform, see Equation 10. Table 9 shows the resulting scores; whereas, Figure 14 gives a graphical depiction of the IAA comparison results.

$$\text{score}(y) = \frac{\text{IAA}(x)}{25} - 5 \qquad \text{Eqn. 11}$$

	Altitude	IAA (10^3 nm^2)	Radius (nm)	Score
Low (RC-135)	35,000	125	195	**0**
Proteus	62,000	220	265	**3.8**
Global Hawk (GH)	65,000	230	271	**4.2**
Sounder	70,000	250	281	**5.0**
Sky Station (SS)	70,000	250	281	**5.0**
Helios	100,000	355	336	**9.2**
High value	105,000	375	344	**10**

Table 9. IAA Score Results

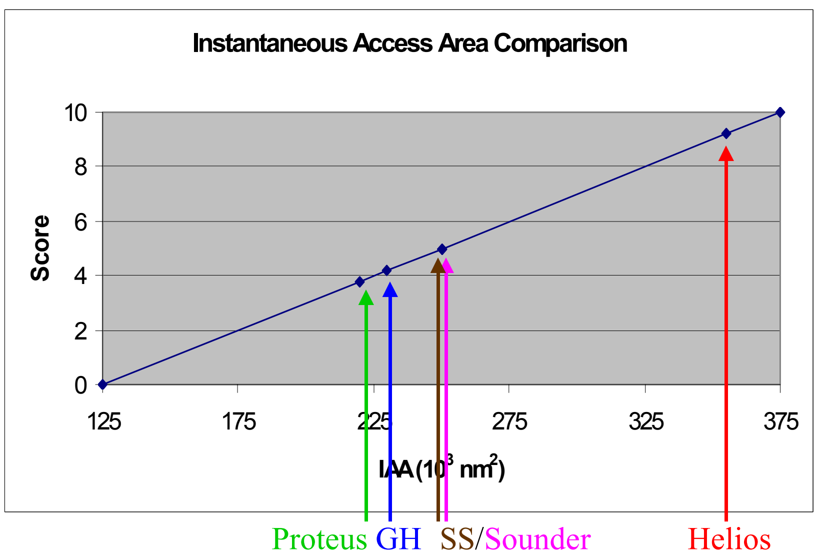

Figure 14. IAA Comparison

2. Cost

As the U.S. military works to modernize its forces, various support and weapons programs will continue to contend for limited monetary resources. Space-based

communications and ISR assets are high cost items that have to compete with weapons programs for military and congressional budget support.

The relatively affordability of HALE platforms is attributed to fewer specialized components and less redundancy. HALE platforms offer potential costs savings by incorporating COTS technologies into both platform and payload design. The use of COTS and GOTS are an essential cost reduction measure, but satellites typically utilize high cost, high-risk developmental items and/or space-qualified parts.

Space systems require numerous special designs such as:

- Hardened electronics to counter the radiation environment
- Special thermal designs to withstand dramatic temperature changes while on orbit
- System redundancy to ensure high reliability because on orbit repairs are not always possible and if possible, costly
- Complex attitude control systems that can keep the spacecraft properly oriented
- Large antennas and/or power requirements to allow sufficient link margins for communications
- Large apertures and antennas to fulfill the ISR roles

Additionally, space provides no launch-on-demand capability for surge operational shortfalls.

The following analysis provides a utility score as a function of cost for current HALE platforms. Cost estimates were obtained via public documents, personal interviews with corporate sponsors, or in some cases, the authors' "best judgment" when no information was available. The authors set their scores at 0 for a high price of $20,000,000 and 10 for a low price of $200,000 for the HALE costs. The range of values led to the selection of a logarithmic utility curve; see Figure 15. Equation 11 was used to compute the cost score, normalized to a value between 0-10. Cost criteria results can be found in Table 10.

$$\mathrm{score}(y) = 10 - \left(5 \bullet \log_{10}\left(\frac{\mathrm{cost}(x)}{200}\right)\right) \qquad \text{Eqn. 12}$$

	Cost ($1000)	Score
High value	20,000	**0**
Global Hawk (GH)	15,300	**0.6**
Sky Station (SS)	10,000	**1.5**
Proteus	8,000	**2.0**
Helios	5,000	**3.0**
Sounder	300	**9.1**
Low value	200	**10.0**

Table 10. Cost Score Results

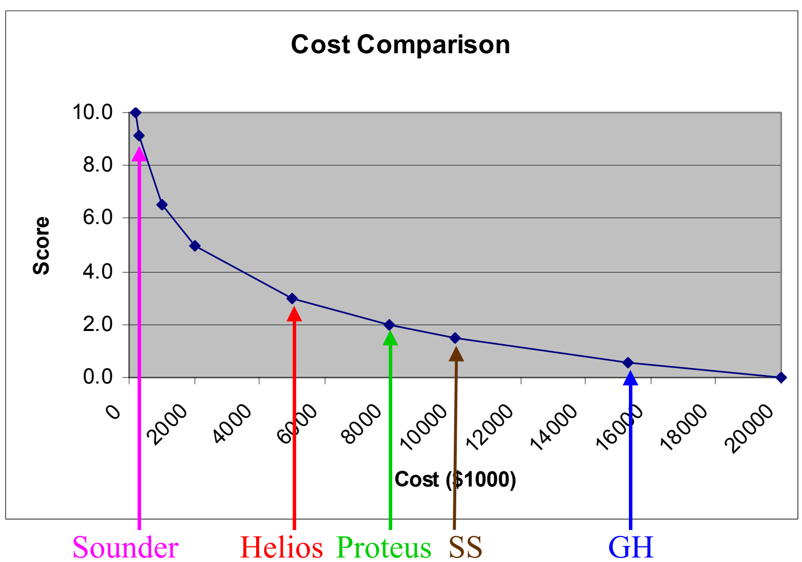

Figure 15. Cost Comparison

3. Endurance

Long endurance is the key to take full advantage of operations in the stratosphere. Ideally, one wants continuous coverage.

The endurance comparison presented here represents the best aspirations of the HALE designers, in most cases. Only the Global Hawk and Proteus have validated flight performance figures thus far.

Endurance score determination was based on the dynamic range of the platforms being analyzed. Proteus helped set the low-end value and Helios the high. Because Proteus was determined to have some utility, the lower end score of 0 was placed at 5 hours. The upper bound score of 10 was set at 5000 hours, which resulted in a logarithmic scale. Upon normalizing the score (y-axis) from 1-10, Equation 12 was derived and used to calculate each platforms endurance score. Table 11 shows the entering arguments and the final results. Figure 16 is a graphical representation of the data.

$$\text{score}(y) = 3.33 \bullet \log_{10}\left(\frac{\text{endurance(x)}}{5}\right) \qquad \text{Eqn. 13}$$

	Endurance (hrs)	**Score**
Low value	5	**0**
Proteus	8	**0.7**
Global Hawk (GH)	36	**2.9**
Sounder	336	**6.1**
Sky Station (SS)	720	**7.2**
Helios	4320 (6 mos)	**9.8**
High value	5000	**10.0**

Table 11. Endurance Score Results

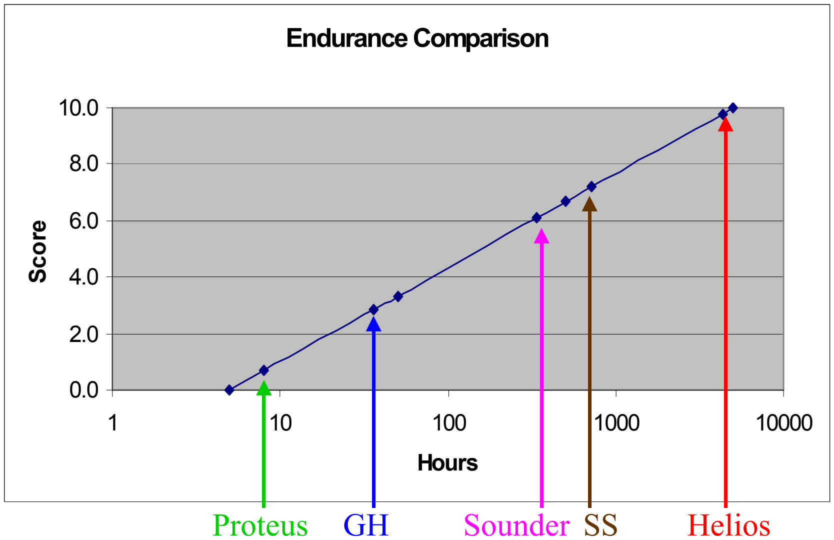

Figure 16. Endurance Comparison

4. Survivability

HALE craft survivability is a major concern. It is assumed that simple protection measures like operating the vehicle at standoff ranges will be utilized; however, UAV's are prime candidate for the dull, dirty, and dangerous missions. Therefore, selection of the best HALE platform should include a comprehensive analysis of vulnerabilities and protection measures.

The analysis presented here is by no means a complete or rigorous vulnerability risk assessment. Proper attention to this subject is a thesis project itself. The authors provide a limited analysis in Chapter VI to help support their assessment of the threat to HALE platforms.

Each of the seven individual measures identified in Table 12 were afforded equal weight in this analysis. Totals are merely the sum of the individual columns. The measures used to determine survivability were graded using the following ordinal scale:

3 = Least vulnerable or Protected
2 = Vulnerable or Marginally protected
1 = Very vulnerable or Not protected

	Global Hawk	Helios	Proteus	Sounder	Sky Station
IR signature	1	3	1	3	3
Radar signature	1	1	1	1	1
Visual signature	3	2	3	1	1
Electronic Protect	3	1	1	1	1
Maneuverability	3	1	3	1	1
Altitude Protect	1	3	1	2	2
Doppler Screen	1	2	1	3	3
Total	**13**	**13**	**11**	**12**	**12**

Table 12. Survivability Factors

The totals on table 12 show that overall, these stratospheric platforms are close in terms of survivability. The ultimate determinant in their survivability results from an analysis of the specific threats faced in a theatre of operations.

The range of possible survivability factor totals was taken and plotted across the x-axis on the graph in Figure 17. After normalizing the resulting scores from 0-10, Equation 13 was used to compute each individual platform score. Table 13 shows the results of the survivability analysis.

Global Hawk and Helios scored highest, but for different reasons. Global Hawk is the more maneuverable asset and has protection features installed. Helios gains its advantage through high altitude protection, and minimal IR signature.

$$\text{score}(y) = \left(\left(\frac{5}{7}\right) \bullet \text{survivability}(x)\right) - 5 \qquad \text{Eqn. 14}$$

	Factor	Score
Low value	7	**0**
Proteus	11	**2.9**
Sounder	12	**3.6**
Sky Station (SS)	12	**3.6**
Global Hawk (GH)	13	**4.3**
Helios	13	**4.3**
High value	21	**10.0**

Table 13. Survivability Score Results

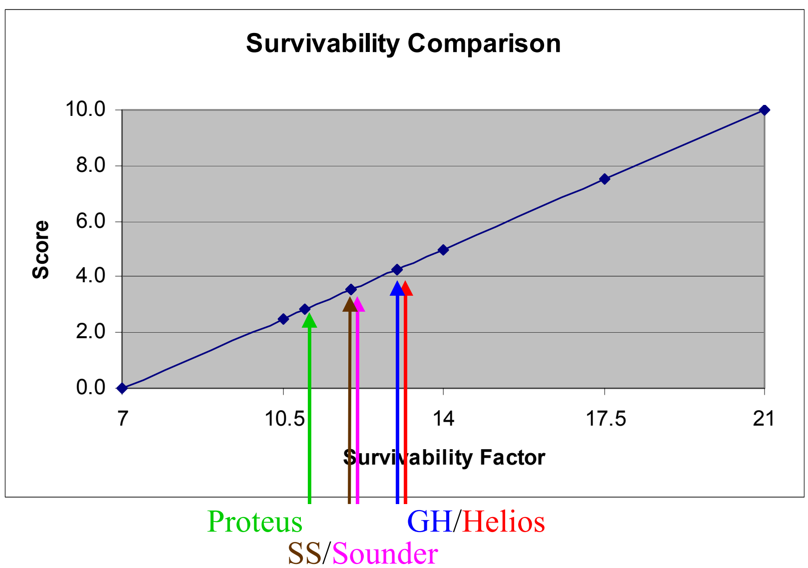

Figure 17. Survivability Comparison

5. Feasibility

Technological feasibility is an important criterion when considering the widening communications bandwidth gap. New systems will have to be brought on-line within the next 5-10 years or else there will be deteriorating support and the inability to move towards a network centric vision. Global Hawk and Proteus share a degree of proven

technology. Helios has demonstrated a high altitude flight up to nearly 100,000 ft, but further development of a nighttime energy storage system is needed. Sounder has made only one short-duration flight, while Sky Station has no prototype available. Figure 18 depicts the authors' judgment, from High to Low, of the technological feasibility of current HALE craft. "High" equates to the most viable near term solution – the system with the least risk.

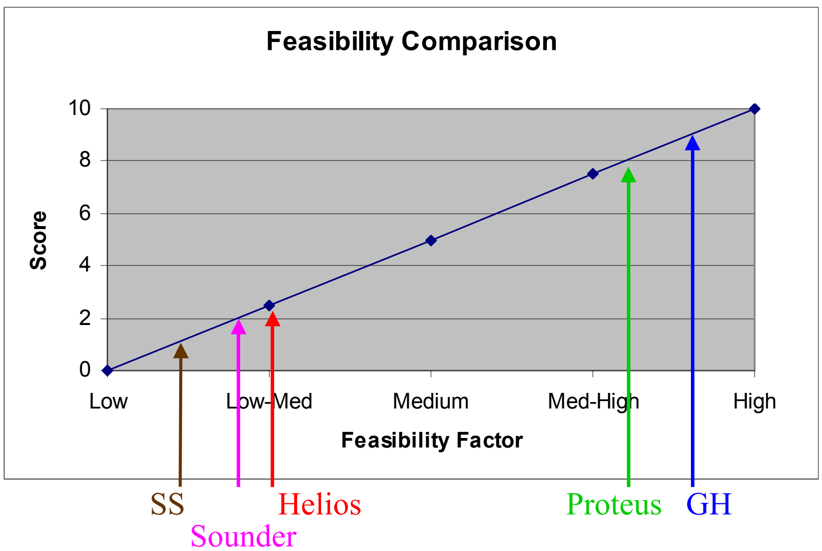

Figure 18. Feasibility Comparison

6. Flexibility

Operational flexibility is one of the stronger arguments for HALE employment. The fact that HALE platforms will be retrievable and reusable makes them well suited to tailored payloads, probably with some sort of plug and play functionality. The theatre commander may want communications equipped HALE craft to provide surge capacity and/or various ISR packages available to support intelligence gathering requirements.

For the purpose of this tradeoff analysis, communications missions were divided into simple comms relay and radio wide area network (WAN). Radio WAN includes netted comms, comms-on-the-move, IP multi-casting and broadcast. Imagery Intelligence was split between EO/IR and SAR, with SAR being the more constraining mission area due to payload weight, size, and complexity. Signal Intelligence capabilities were subdivided into detection and geo location. A system's detection capability is based on frequency coverage; specifically, the number, size, and weight of RF tuners and antennas that the platform can support. Single platform geo location techniques typically require aircraft motion.

The scoring of this category is the authors' judgment. The authors scored each mission area to determine the overall measure of the platforms flexibility. Mission areas were equally weighted, thus results are obtained by merely summing the individual columns. The following ordinal scale was used:

3 = Capable
2 = Marginal
1 = Not capable

Table 14 shows the totals for each platform. The range of the possible totals were plotted and normalized to generate the plot found on Figure 19. Flexibility scores were calculated using Equation 14.

	Global Hawk	**Helios**	**Proteus**	**Sounder**	**Sky Station**
Communications					
Relay	3	3	3	2	3
Radio WAN	3	3	3	1	3
IMINT					
EO/IR	3	3	3	3	3
SAR	3	1	2	1	1
SIGINT					
Detection	3	3	3	2	3
Geo Location	3	1	2	1	1
Total	**18**	**14**	**16**	**10**	**14**

Table 14. Flexibility Factors

$$\text{score}(y) = \left(\left(\frac{5}{6} \right) \bullet \text{flexibility}(x) \right) - 5 \qquad \text{Eqn. 15}$$

Table 15 shows the results of the flexibility analysis scoring. Boundaries were set with a low factor of 6 equal to 0 and a high factor of 18 equal to 10. Global Hawk was determined to be more flexible than Sounder due to the number of different payloads, and thus, mission areas it can support. Sounder has serious weight and size constraints that hurt its ability to flex to the theatre commander's required mission needs. The airships and Helios were determined incapable of Spot Mode SAR because of their slow airspeed. For similarly reasons, these platforms were considered incapable of providing single platform SIGINT geo location.

	Factor	**Score**
Low value	6	**0**
Sounder	10	**3.3**
Helios	14	**6.7**
Sky Station (SS)	14	**6.7**
Proteus	16	**8.3**
Global Hawk (GH)	18	**10.0**
High value	18	**10.0**

Table 15. Flexibility Score Results

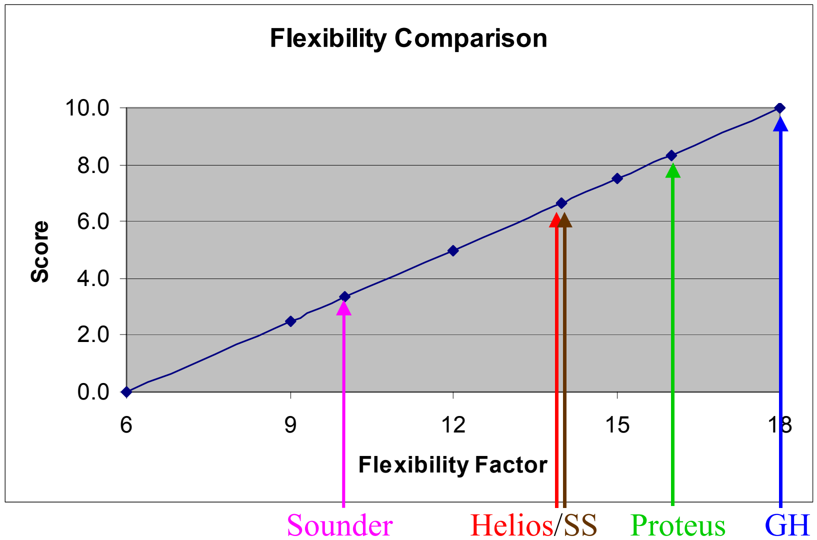

Figure 19. Flexibility Comparison

7. Responsiveness

HALE craft will be called upon to augment satellite assets in crisis situations. Therefore, they must be capable of rapid deployment to theater, expeditious employment to on-station, and dynamic re-orientation if already on-station. A definition of the responsiveness factors follows:

- Deployable – the time it takes to relocate the asset into theater from the time the operation order is giving.
- Employable – the time it takes to launch the asset from the forward deployed base until on-station. A function of launch and airspeed.
- Dynamic re-tasking – the time it takes to reposition the asset to a different operational area. A function of airspeed.

The authors either objectively or subjectively scored each category based on their knowledge of operational support requirements and airspeed metrics. Weights were

added by the authors to stress the deploy ability measure. In order for the CINC to employ the asset or dynamically re-task it, the platform must first be capable of getting into theatre. Deployability was determined to be twice as important as re-tasking.

Responsiveness factor totals, found in Table 16, were based on the following ordinal scale measurements:

3 = Best or Most capable
2 = Capable
1 = Worst or Incapable

	Weight	Global Hawk	Proteus	Helios	Sounder	Sky Station
Deployable	2	2 x 2	2 x 2	1 x 2	3 x 2	1 x 2
Employable	1.5	3 x 1.5	2 x 1.5	1 x 1.5	1 x 1.5	1 x 1.5
Dynamic Re-tasking	1	3	2	1	1	1
Total		**11.5**	**9**	**4.5**	**8.5**	**4.5**

Table 16. Responsiveness Factors – Measurements and Weights

Sounder was determined to be the most deployable. The authors envision the disposable Sounder airship forward deployed, sitting in a crate ready for employment at any time. All the other HALE craft will most likely be flown into theatre. Some will take longer than others based on maximum airspeed and other support factors.

Global Hawk was deemed most responsive because of its maneuverability and airspeed capabilities. The airships, and Helios are just too slow and thus warrant lower marks.

Responsiveness factor totals were normalized and plotted. Equation 15 was used to calculate the final responsiveness score for each platform. Table 17 shows score results, whereas Figure 20 gives a graphical representation of the responsiveness results. Boundaries were set with a factor of 3 equal to 0 and a factor of 15 equal to a score of 10.

$$\text{score}(y) = \left(\left(\frac{5}{6}\right) \bullet \text{responsiveness}(x)\right) - 2.5 \qquad \text{Eqn. 16}$$

	Factor	Score
Low value	3	**0**
Sky Station (SS)	4.5	**1.3**
Helios	4.5	**1.3**
Sounder	8.5	**4.6**
Proteus	9	**5.0**
Global Hawk (GH)	11.5	**7.1**
High value	15	**10.0**

Table 17. Responsiveness Score Results

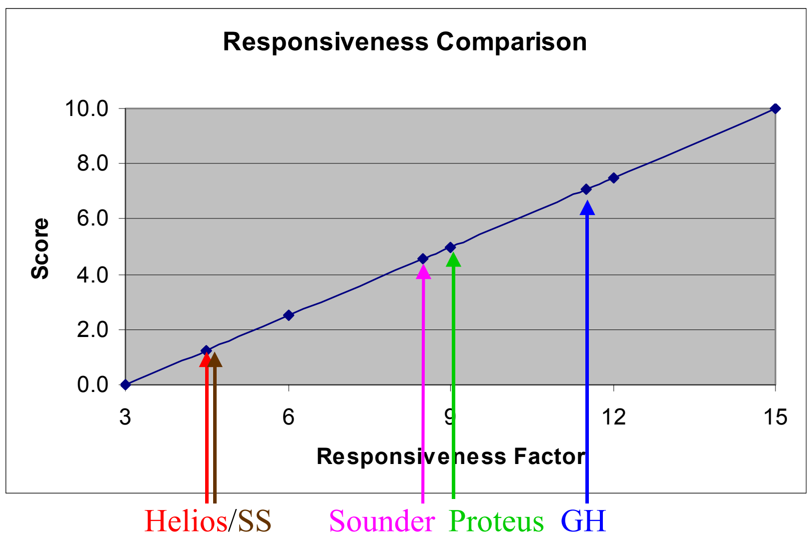

Figure 20. Responsiveness Comparison

E. HALE ANALYSIS SUMMARY

As a result of the HALE platform comparison analysis, it is recommended that Global Hawk fulfill the near term HALE requirement and that Helios should be considered as a long-term solution.

1. Near Term

The importance of fielding a HALE platform in the near term, the next 5-10 years, led the authors to weighting feasibility higher than any other criteria. Additionally, it was felt that the system should offer good survivability and flexibility at an affordable cost. For the purpose of this analysis, less importance was placed on the remaining factors. Table 18 and Figure 21 show the overall results of the near term analysis.

Global Hawk is the clear winner of the near term analysis, mostly due to its high marks in feasibility and flexibility. But, keep in mind; the weights here are based solely on the authors' view given the need to procure a near term fix. An actual Analysis of Alternatives would involve gaining the user's perspective at ever step in the System Engineering Process, especially, during the tradeoff process. A more complete analysis would make for an excellent follow-on thesis subject.

	IAA	Cost	Endurance	Survivability	Feasibility	Flexibility	Responsiveness	**Total**
Weight	**4**	**6**	**4**	**6**	**7**	**6**	**4**	
Global Hawk	**16.8**	**3.5**	**11.4**	**25.7**	**63.0**	**60.0**	**28.3**	**208.8**
Helios	**36.8**	**18.1**	**39.1**	**25.7**	**17.5**	**40.0**	**5.0**	**182.2**
Proteus	**15.2**	**11.9**	**2.7**	**17.1**	**56.0**	**50.0**	**20.0**	**173.0**
Sounder	**20.0**	**54.7**	**24.3**	**21.4**	**14.0**	**20.0**	**18.3**	**172.8**
Sky Station	**20.0**	**9.0**	**28.7**	**21.4**	**7.0**	**40.0**	**5.0**	**131.2**

Table 18. Matrix Results – Near Term Solution

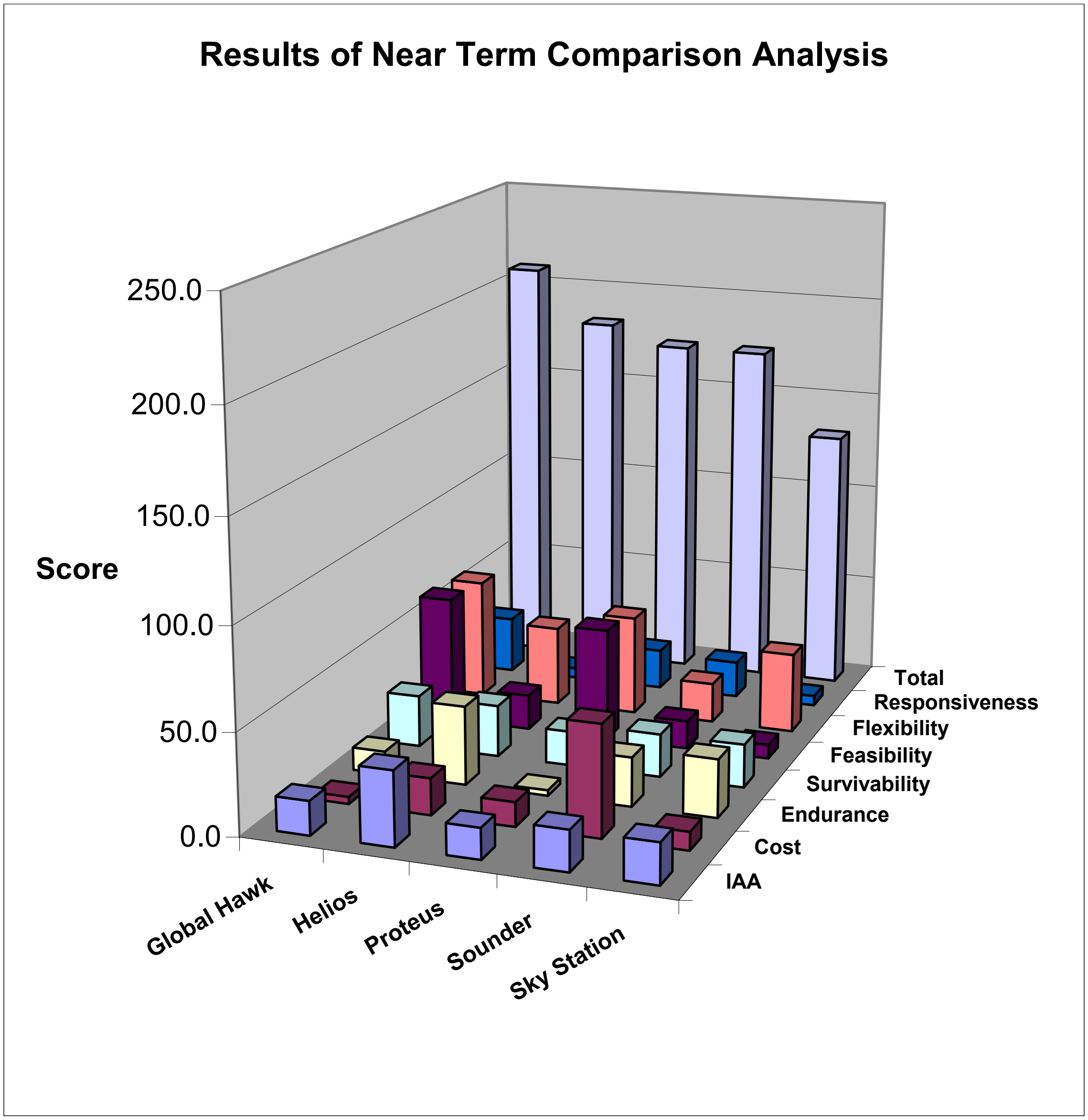

Figure 21. Comparison Analysis Results – Near Term Solution

2. Long Term

Long term results differ because of the weighting effect. Emphasis here was placed on a true High Altitude, Long Endurance vehicle. To that end, IAA and endurance were afforded the greatest weights. The platform was envisioned being utilized primarily in the communications role at standoff ranges. Cost and feasibility rated higher than the remaining categories. Table 19 and Figure 22 display the result of the long term look.

The Helios solar powered UAV came out on top due to high totals in the two most highly weighted categories, IAA and endurance.

	IAA	Cost	Endurance	Survivability	Feasibility	Flexibility	Responsiveness	**Total**
Weight	**6**	**5**	**6**	**4**	**5**	**4**	**4**	
Global Hawk	**25.2**	**2.9**	**17.1**	**17.1**	**45.0**	**40.0**	**28.3**	**175.7**
Helios	**55.2**	**15.1**	**58.7**	**17.1**	**12.5**	**26.7**	**5.0**	**190.2**
Proteus	**22.8**	**9.9**	**4.1**	**11.4**	**40.0**	**33.3**	**20.0**	**141.6**
Sounder	**30.0**	**45.6**	**36.5**	**14.3**	**10.0**	**13.3**	**18.3**	**168.1**
Sky Station	**30.0**	**7.5**	**43.1**	**14.3**	**5.0**	**26.7**	**5.0**	**131.6**

Table 19. Matrix Results – Long Term Solution

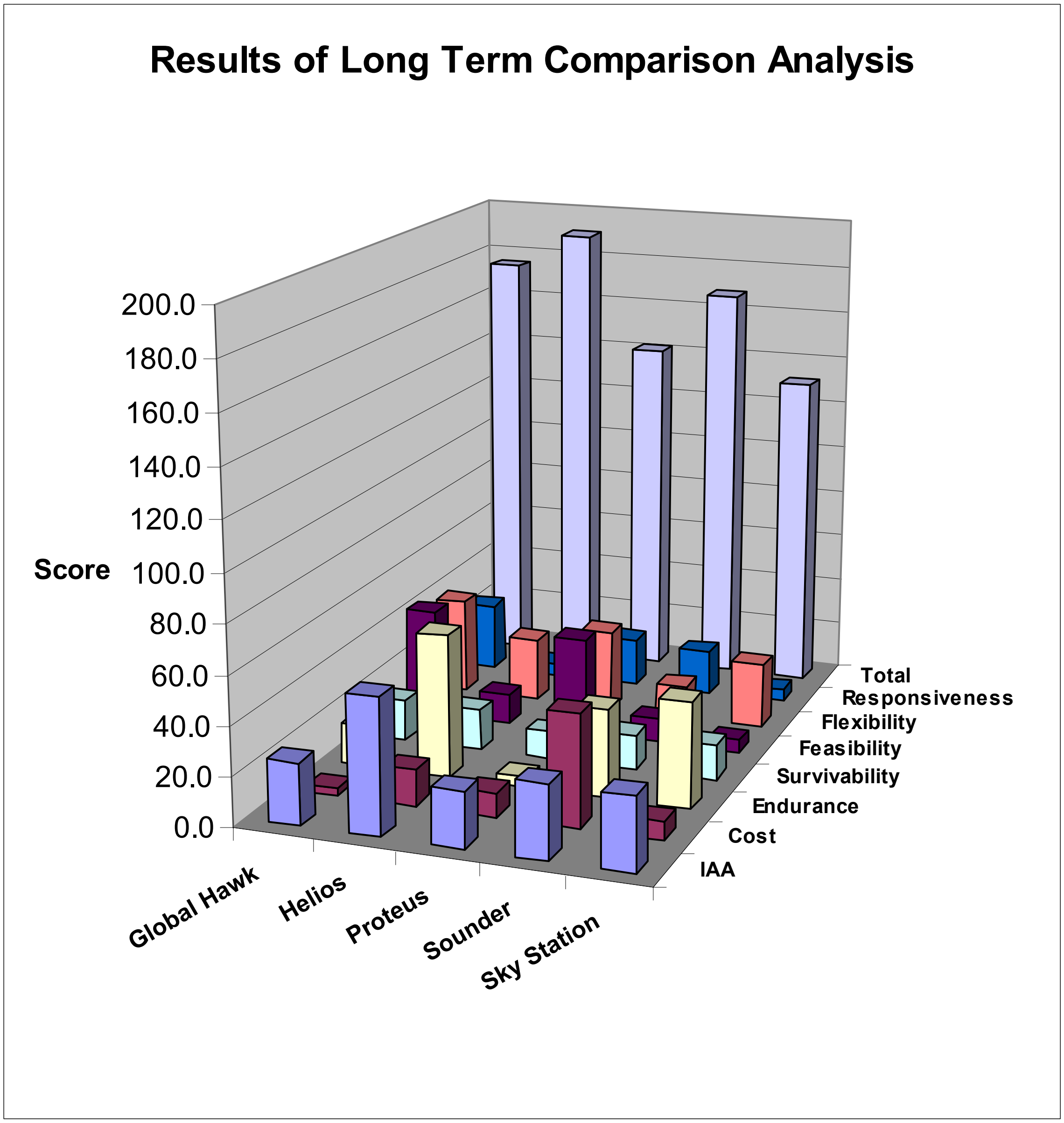

Figure 22. Comparison Analysis Results – Long Term Solution

The conclusions that the authors arrive at from this comparative analysis are based on their own judgment and the limited data from the various HALE programs. Other studies would likely draw different conclusions, given additional data and the combined judgment of the warfighter.

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IX. CONCLUSIONS

In this final chapter a summary is provided on the breadth of the research and analysis conducted in the area of HALE platforms. Secondly, the authors provide their general conclusions concerning the unique potential that HALE platforms offer US forces both in the near and far terms as they transition to the Network Centric Environment. Finally, general recommendations are given that the Navy and Marine Corps should adopt in order to provide both a vision for the future and a strategy for developing effective HALE systems that will provide both the best support and best "bang-for-the-buck".

A. SUMMARY

This thesis begins with a description of the armed services future needs in term of communications and ISR support as they relate to their warfighting doctrines. An overall assessment of the requirements and deficiencies was included concerning the available communications and ISR support. Secondly, the current SATCOM and ISR assets were reviewed to provide the supporting documentation about what is actually available to the warfighter. Thirdly, there is extensive analysis provided on the advantages of utilizing HALE platforms from stratospheric heights. Fourth, a general description of ongoing HALE programs is given in terms of their phase in development, strengths, weaknesses, and challenges. Sixth, there is a chapter devoted to the survivability capabilities of HALE craft. Finally, two chapters are devoted to trade-off analysis between the various HALE systems and their envisioned CONOPS.

B. CONCLUSIONS

There are a number of conclusions that the authors arrived at during the course of the research. The following are those considered most pertinent.

The first and probably most important is that future warfighting doctrines cannot be effectively implemented, either fiscally or technologically, without capabilities that HALE type platforms provide. The stratosphere offers unmatched niche capabilities in many mission areas.

Secondly, in terms of the most viable options from HALE support, the authors have made the following conclusions in terms of priorities:

- The Global Hawk offers the most feasible option in HALE capabilities for communication and ISR because it is a fully funded and validated system. It is the closest HALE platform nearing operational employment and offers global reach.
- Proteus type platforms provide the next best solution for near term augmentation to the Global Hawk because it is also proven technology. In terms of payload, they have the capacity for large antennas, which benefit the mobile user. Secondly, in terms of self-deployability and potential overflight issues, a manned aircraft can offer advantages over UAV's requiring support elements.
- The Helios type platforms offer the next most likely long-term option for a continuous airborne asset. It has validated its flight regime capabilities and only needs to overcome nighttime power issues. It's recent record flight at 96,500 ft validated the capability to operate in that regime and provide advantages in coverage over other stratospheric systems
- Finally, the authors have concluded that solar powered airships, such as Sounder, will be the most difficult platforms to develop because they face the most difficult technological challenges. Though they do offer potential and affordable support to the tactical commanders in expanding their battlespace communications and ISR support, they also will be the least flexible platform in terms of range of operation.

Thirdly, further analysis is required to determine if the overall C4ISR architecture should include a variety of HALE platforms because each has weaknesses in supportability. For example, Helios offers the potential for uninterrupted coverage but cannot support winter operations at high latitudes. Global Hawk and Proteus offer global access but include a larger logistic support system and shorter duration flights. Finally, Sounder offers affordable tactical assets to front line units but is a less flexible expendable.

Fourth, the authors have concluded that HALE platforms are particularly useful to operations at sea and in the littorals. The freedom of movement through international airspace and lack of terrain obstructions enable maximum effectiveness of stratospheric platforms.

Finally, the authors have concluded that the Navy and Marine Corps are not devoting sufficient money, personnel, or focus on emerging HALE systems to get a quality product to the fleet in the near future. A report by *Defense Week* recently stated that the "Navy planners are taking a wait-and- see-approach: incorporating technologies already being developed by the Air Force into the sea service's own operational needs and developing its own capabilities when other systems fall short, said the chief of Navy UAV systems". [Low01] This lack of focus is evident in the fact that the Naval Service has a stated need to integrate UAV's into its communications and ISR structure but yet does not have a mission statement concerning the types, numbers, or capability requirements for these systems.

C. RECOMMENDATIONS

There are a number of specific actions that can be taken to ensure that the Navy and Marine Corps can leverage these emerging systems for their use. They include a two-prong approach towards a Network Centric Capability. The first involves actions in the development of HALE platforms and the second is a parallel approach in developing the interoperable payloads that can be carried on the HALE systems.

In terms of HALE development, the following actions are recommended:

- First, and probably most important, the Navy and Marine Corps need to provide a vision statement and plan for leveraging HALE systems for their warfighting needs. There are currently programs in both services studying and developing lower altitude aircraft and UAV's for communications and ISR support but none yet specifically on the HALE platforms covered in this research. This vision should include both short and long term plans.
- The second recommendation involves more active participation in the development of current HALE platforms, specifically the Global Hawk.

To ensure that the Global Hawk will be fully interoperable with Navy and Marine Corps C4ISR architectures, it is imperative that the Navy and Marine Corps have more input in its development. An operational plan for its implementation is needed in terms of missions, required aircraft, and command structures to facilitate real-world support.

- Third, the services should take a more active role in monitoring commercially developing stratospheric nodes for potential military applications. The Helios and Proteus are examples of these systems.

In the payloads area, the services need to develop communications and ISR equipment that will be adaptable and scalable for the variety of HALE systems in development.

In the ISR area equipment should include:

- Lightweight high-resolution digital imagers that are easily installed
- Maximum use of COTS technology that can provide adequate support and affordable prices

In the communications area the equipment should include:

- Router-to-router capabilities for all systems to provide the plumbing needed for networking.
- Protocol development that will enable multi-casting networks for widespread user support
- Airborne Communications Nodes (ACN) capabilities able to process a variety of digital frequencies and retransmit on all frequencies used by the warfighters in theatre
- Systems that will allow integration with current digital communications gear

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